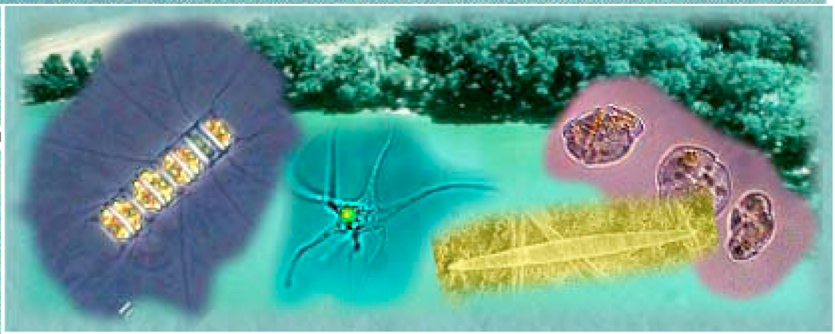

Harmful Algal Blooms (HABs) are of national concern because they adversely affect not only the health of people and marine organisms, but also the "health" of local and regional economies. Health effects range from cell damage to organism mortality through such mechanisms as toxin production and localized conditions of low oxygen. For the past several decades, harmful algal blooms have caused more than $1 billion in losses in the United States, with resources diverted to monitoring programs, closures of shellfish beds and coastal fisheries, severe reductions in local and regional tourism and associated service industries, public illness, and medical treatments and advisories. Harmful algal blooms occur in almost every U.S. coastal state; examples include toxin-producing dinoflagellates in New England, the mid-Atlantic, the Gulf of Mexico, the entire West Coast including Alaska, and tropical and subtropical states and possessions; toxic diatoms in the Gulf and along the West Coast; and toxin-producing flagellates and gill-clogging diatoms in the Pacific Northwest. Research, monitoring, and education efforts focus on ways to mitigate and prevent future outbreaks of harmful algal blooms.

The following reference format is suggested:

Bushaw-Newton, K.L. and Sellner, K.G. 1999 (on-line). Harmful Algal Blooms. In: NOAA's State of the Coast Report. Silver Spring, MD: National Oceanic and Atmospheric Administration. http://state-of-coast.noaa.gov/bulletins/html/hab_14/hab.html

For questions on figures or photographs used in this essay, contact Kevin Sellner, Center for Sponsored Coastal Ocean Research, National Oceanic and Atmospheric Administration, Silver Spring, MD 20910

STATE OF THE COASTAL ENVIRONMENT

HARMFUL ALGAL BLOOMS

INTRODUCTION

Throughout the world's coastal oceans, observations of harmful algal blooms (HABs) are being reported with increasing frequency. Often, these events are accompanied by severe impacts to coastal resources, local economies, and public health. Harmful algal blooms -- accumulations of microscopic species of algae or the larger, multicellular species -- appear to be more devastating than ever before, and may be increasing over time. Some species recur in the same geographic regions each year, while others are episodic, leading to the unexpected deaths of local fish, shellfish, mammals, and birds. While the impacts appear to be both obvious and on the rise, only about 50 of the thousands of known algal species actually produce toxins. Some of these toxins have direct and deleterious effects on local plants and animals; others have indirect affects on organisms by changing local environmental conditions.

In general, most harmful algal blooms are caused by plants (photosynthetic organisms) that form the "base" of the food chain. These include both microscopic species of algae, referred to scientifically as phytoplankton and the microphytobenthos, as well as the larger macroalgae. Other HABs are caused by accumulations of nonchlorophyll-containing cells (heterotrophs) that are similar in form to microscopic algae. A bloom occurs when an alga or heterotroph rapidly increases in numbers to the extent that it dominates the local planktonic or benthic community. Such high abundance can result from explosive growth, caused, for example, by a metabolic response to a particular stimulus (e.g., nutrients or some environmental condition like a change in water temperature), or from the physical concentration of a species in a certain area due to local patterns in water circulation. The similarity of these alga and heterotrophs often makes it difficult to identify the precise cause of a harmful algal bloom, and to predict its impact on the affected ecosystem.

It is a challenge to define a harmful algal bloom and to characterize the species that causes it. All HABs were once referred to as "red tides" because of the color imparted by algae suspended in the water, but the description has since become a misnomer because not all HABs are red (some may be brown, yellow, or green), and some may not discolor the water at all. Color is imparted through cellular concentrations of pigments like chlorophyll or lower abundance pigments. Examples of HABs that are readily associated with water discoloration are blooms of many species of cyanobacteria, generally visible as floating green scums or colonies in coastal environments; two "brown tide" species (*Aureococcus* and *Aureoumbra*) that turn coastal lagoons dark chocolate brown; the dinoflagellates *Alexandrium* spp., *Gymnodinium breve,* and *Noctiluca* spp., that cause red water; and blooms of macroalgae. However, no color is visible in other harmful species, such as the chlorophyll-free dinoflagellate *Pfiesteria piscicida* , several *Dinophysis* species, and benthic microalgae (e.g., *Gambierdiscus*) that grow on the surfaces of larger macoroalgae in tropical waters. Both *Pfiesteria* and *Dinophysis* also impart toxicity at very low densities, generally less than 1,000 cells per liter (Burkholder and Glasgow 1997, Smayda 1997). In comparison, macroalgae are considered harmful due to dense overgrowth that can occur in localized areas, such as coral reefs of the tropics or coastal embayments receiving excessive nutrient loading (LaPointe 1997, Valiella et al. 1997). Accumulations can be so high as to cover the bottom of a region, excluding other biota as well as creating an environment in which high oxygen consumption and the associated anoxic conditions accompany decomposition of the accumulated or displaced biomass.

(top)

Photo 1. A bloom of *Noctiluca* colors the seawater in a phenomenon commonly known as "red tide." At about two millimeters in

Detrimental Effects of Harmful Algal Blooms

diameter, *Noctiluca* is the largest of the dinoflagellates.

The detrimental effects of a harmful algal bloom can range from cell and tissue damage to organism mortality, and can be caused by a number of mechanisms, including toxin production, predation, particle irritation, induced starvation, and localized anoxic conditions. As a result, a bloom may affect many living organisms of the coastal ecosystem, from zooplankton to fish larvae to people.

Toxins. As noted above, only a few HAB species actually produce toxins that are poisonous to people and marine animals. The most well known HAB toxins are generically referred to as ciguatera fish poisoning (CFP), neurotoxic shellfish poisoning NSP), paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP). *Pfiesteria piscicida* also produces two toxic fractions, dermonecrotic and neurologic toxins that impact fishes and humans (Bever et al. 1998, Grattan et al. 1998) (Lowitt and Kauffman 1998) (Noga et al. 1996). Cyanobacteria also produce similar toxins that overlap with several of these general categories, including neurotoxins and hepatoxins.

Symptoms of exposure to these toxins include gastrointestinal, neurological, cardiovascular, and hepatological symptoms. The algae that produce these toxins, and the specific symptoms they cause, are summarized in Appendix A. The terms "fish" and "shellfish" are associated with these illnesses because the toxins concentrate in the fish and shellfish that ingest the harmful algae; people and marine mammals may be poisoned when they consume the affected seafoods.

Other harmful algal blooms produce toxins with no identifiable effects on humans but devastating impacts on coastal living resources. For example, the flagellate *Heterosigma akashiwo* is thought to produce an ichthyotoxin that kills fish (Taylor and Horner 1994), resulting in significant threats to penned fish in mariculture operations.

Predation. Predation is another way that several HAB species can impact coastal biota. Predation occurs when one organism captures or feeds on another organism. One example of a predatory HAB is *Pfiesteria piscicida*. There is accumulating evidence that this dinoflagellate produces several toxic "fractions" that assist in prey capture. Two of these toxic fractions are produced after the *P. piscicida* is exposed to fish secretions. The first fraction has neurotoxin-like properties that affect the fish's neurological system. The second has skin-killing (dermonecrotic) characteristics. The neurotoxin-like materials cause lethargy in the fish, and, when present in sufficient quantities, death. The dermonecrotic compounds apparently cause sloughing of the external skin layers, leading to lesions and perhaps secondary infections from fungi and other pathogens in the surrounding water. Fish kills coincident with *Pfiesteria* are likely to be a result of direct exposure to toxic compounds produced by the dinoflagellate, secondary infections associated with lesions, or a combination of both (Noga et al. 1996, USEPA 1998). Fish mortality is then followed by dinoflagellate ingestion of fish tissue.

Photo 2. These lesions, believed to be caused by toxins produced by the dinoflagellate *Pfiesteria piscicida* , make fish such as these menhaden vulnerable to secondary infections.

(top)

Particle Irritation. Several HAB species, specifically two spine-forming diatoms (*Chaetoceros cavicornis* and *C. convolutus*), also cause significant problems for coastal fish that are commonly produced in mariculture operations. The deaths of fish and crustaceans occur because large numbers of these spiny phytoplankton become trapped in the animals' gills, resulting in mucus accumulation and respiratory failure, hemorrhaging, and bacterial infection (Rensel 1993b).

Induced Starvation. HABs can cause organisms to starve through nutritional and size mismatch (Smayda 1997). Organisms that ingest HABs are often unable to ingest enough high-quality food to survive. The brown tide organism *Aureococcus* reduced ingestion of nutritious algae in bay scallop larvae by interfering in the scallops' ciliated esophagus (Gallager et al. 1989). In adult suspension-feeding bivalves, the alga inhibits the activity of lateral cilia in the gill, the main organ of particle capture (Gainey and Shumway 1991), ultimately reducing growth (Bricelj et al. 1999). Other HAB species may be too small, too big, taste badly, or, as in the ingestion of *Prorocentrum minimum* by oyster larvae or spat, alter the absorption capabilities of the organism's digestive system (Wikfors et al. 1995). Bloom densities of *P. minimum* actually kill juvenile oysters (Luckenbach et al. 1993) and bay scallops, possibly by interfering in the shellfishes' ability to produce digestive enzymes or by causing atrophy of the digestive tissue (Wikfors and Smolowitz 1993, 1995).

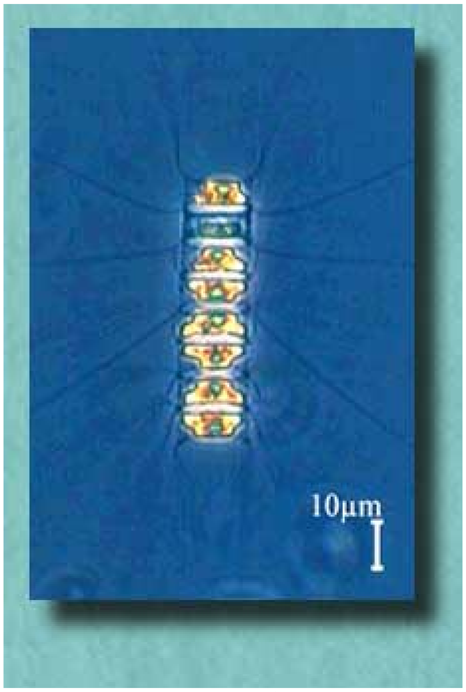

Photo 3. This algae species of the genus *Chaetoceros* kills with its spiny, serrated filaments, which clog the gills of fish that feed on them.

Localized Anoxic Conditions. Excessive accumulations of algae, whether as a micro- or macroalgal bloom, are often followed by high decomposition rates of the accumulated material. The decomposition is accompanied by oxygen consumption, stripping local waters of available oxygen and leading to hypoxia (low oxygen) or anoxia (no oxygen). Without oxygen, most marine biota cannot survive, resulting in mass mortalities of fish and shellfish. Crustacean deaths occur because large numbers of algal cells become trapped in the creatures' gills, causing respiratory failure, hemorrhaging, or bacterial infection (Smayda 1997). Species of the diatom genus *Chaetoceros,* for example, become lodged in the gills, where their spiny filaments destroy the hosts' tissue.

Historical Context

Harmful algal blooms are not new phenomena, with written references dating back to Biblical times. Dinoflagellates have been found in the fossil record for millions of years, and cyanobacteria were the first photosynthetic life forms on Earth. According to Dr. Don Anderson, who researches algal species at the Woods Hole Oceanographic Institute in Massachusetts, "There are more toxic algal species, more algal toxins, more fisheries resources affected, more food-web disruption, and more economic losses from harmful algal blooms than ever before" (Anderson et al. 1993) (Figure 1). The interest in HABs stems, in large part, from increased public awareness of the negative impacts to marine resources, e.g., strandings and deaths of marine mammals, birds, and sea turtles; increased monitoring efforts and improved methods of detection; and the establishment of linkages between initial exposure and subsequent symptoms displayed by organisms exposed to a HAB species. Understanding the ecology and oceanography of these species, and how they affect other organisms, including people, continues to be a challenge for researchers. In 1995, a federal interagency program known as

ECOHAB (Ecology and Oceanography of HABs) was initiated to support HAB research in the United States (Anderson 1995).
(top)

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HARMFUL ALGAL BLOOMS

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NATIONAL PICTURE

Harmful algal blooms are having significant impacts on coastal areas of the United States and the rest of the world, affecting the health of both humans and marine organisms and the vitality of local and regional economies. Their presence and persistence represent a significant and expanding threat to human health and marine resources across the nation (Anderson et al. 1993). The numbers and diversity of reported HAB incidents have increased during the past 25 years (Figure 2) to include almost every U.S. coastal state. Understanding the causes of these phenomena, and mitigating and preventing their consequences, are national concerns.

Most harmful algal blooms result from the transport of offshore populations to inshore regions, i.e., physical relocation independent of human activities. Examples of the importance of water circulation and bloom events abound. The largest blooms observed, those of *Trichodesmium* in the open ocean, occur far from any coastal inputs (Sellner 1992, 1997). In the Baltic Sea, summer blooms of *Nodularia* and *Aphanizomenon* have occurred since late in the last century, likely due to the mixing of regenerated nutrients from depths below the seasonal and permanent pycnoclines during meteorological events, or from mixing events induced by North Sea inflows (Sellner 1992, 1997, Kononen and Nommann 1992). The organisms responsible for diarrheic shellfish poisoning, *Dinophysis* spp., are often swept into coastal rias and river mouths through wind-induced upwelling (Pazos et al. 1995). Blooms of *Alexandrium tamarense*, responsible for paralytic shellfish poisoning (PSP) in people, are often initiated when cells are transported into the Gulf of Maine from the eastern provinces of Canada, and then further south into Massachusetts Bay (Anderson 1997). Blooms of *Gymnodinium breve,* responsible for neurotoxic shellfish poisoning, occur when cells from small, offshore populations in the open Gulf of Mexico are advected onto the west Florida shelf and into the coastal waters of other states bordering the Gulf of Mexico, and even into North Carolina estuaries (Tester and Steidinger 1997, Dortch et al. 1998). The dinoflagellate *Gyrodinium aureolum*, producing compounds that narcotize fish gills and congest bronchial blood vessels, is transported into Norwegian fjords from offshore populations (Lindahl 1986, Dahl and Tangen 1990). This consistent delivery of many HABs from offshore to inshore regions produces an aperiodic infusion of potentially dangerous HABs into most areas of the world's coastal oceans, even those that are independent of human actions on shore or coastal watershed activities. As a result, attempts to prevent HAB events are somewhat impractical, because people cannot control general oceanic ciruclation or even localized coastal currents.

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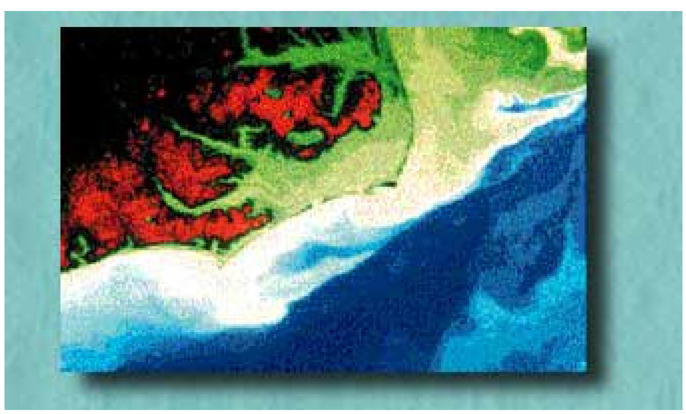

Photo 4. The "Gulf Stream" (dark blue) from the Gulf of Mexico to the Atlantic Ocean can transport large populations of the dinoflagellate *Gymnodinium breve* to near-coastal waters such as here off the outer banks of North Carolina.

The Consequences of Harmful Algal Blooms

The expansion of harmful algal blooms during the past 20 years is responsible for losses approximating $100 million per year nationwide (Turgeon et al. 1998). After an outbreak, not only are health issues a major concern, but many industries also are affected (Figure 3). Closures of shellfish beds, lost production in fisheries (both aquaculture and wild), severe reductions in local/regional tourism and associated service industries, public illness, and medical treatments and advisories result in the loss of millions of dollars per outbreak. For fisheries-related businesses, insurance rates increase, unemployment and bankruptcies rise, and retail sales typically decline for all seafood species; at the same time, public resources are diverted to monitoring programs.

Photo 5. Outbreaks of harmful algal blooms can kill thousands of fish and cost millions of dollars in lost fisheries revenues.

The direct and indirect losses attributed to HAB events are staggering to the local areas in which they occur. A single outbreak of paralytic shellfish poisoning in the Northeast was estimated to cost $6 million (Shumway 1988). The 4- to 6-month red tide in North Carolina during 1987-1988 was estimated to have cost the community $25 million (Tester and Fowler 1990). The 1991 outbreak of domoic acid/amnesic shellfish poisoning in Washington had a negative impact on the entire community, from the tourism industry to unaffected fisheries (oysters), with losses estimated between $15 and $20 million. In North Carolina, recent outbreaks (1995 and 1996) of *Pfiesteria piscicida* and *Pfiesteria* -like dinoflagellates have resulted in the deaths of millions of fish, including the commercial menhaden, due to secondary infections and/or toxins (Burkholder and Glasgow 1997). In addition, a recent outbreak of *Pfiesteria* or *Pfiesteria* -like organisms in the Chesapeake Bay resulted in a public outcry, an estimated $43 million loss for the seafood industry, and several reported incidents of illness in people (Sieling and Lipton 1998).

Even a nontoxic harmful algal bloom can have devastating effects on a natural community. In South Florida, blooms of macroalgae are overwhelming sections of coral reef ecosystems and seagrass beds (LaPointe 1997). Besides being one of the most productive and diverse marine ecosystems, coral reefs are a vital component of the South Florida economy, attracting thousands of visitors each year. Seagrass beds are important nursery habitat for pink shrimp, spiny lobster, and finfish. Continued overgrowth of algae could eliminate these refuges of biodiversity and lead to severe economic losses for the recreation and tourism industries. In Long Island, brown tide severely impacted the bay scallop industry (Nuzzi and Waters 1989) with the collapse and permanent loss of the $2 million per year industry. In Washington, *Heterosigma akashiwo* blooms have caused losses of $4 to $5 million per year to harvesters of wild and penned fish (Horner et al. 1997). Finally, in the same region, economic losses due to blooms of *Chaetoceros,* which mainly affect penned fisheries, are estimated to result in losses of about $500,000 per episode (Rensel 1993a).

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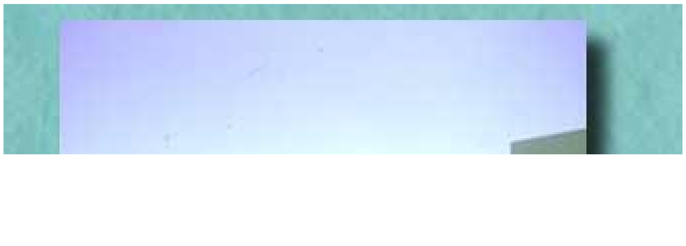

Photo 6. Blooms of macroalgae, like this outbreak of *Codium isthmocladum* that washed ashore in Florida, choke the seagrass beds, cause oxygen depletion in the water, and result in losses to the recreation and tourism industries.

Possible Causes of the Increase in Harmful Algal Blooms

The frequency, duration, and intensity of algal blooms are related to a number of biological, chemical, and physical factors, although, many of these complex relationships have not yet been identified. Four possible reasons have been advanced for the increased frequency and expanding geographic occurrence of HABs. First are improved methods of detection and greater monitoring efforts. These increase the probability that a HAB species will be recorded. Second is the introduction of exotic species via ballast water exchange or aquaculture practices (Hallegraeff 1993). A third possibility is that blooms result when grazers fail to control the algal species' growth (Smayda 1990). Fourth, blooms may result from climate changes, as well as human activities, such as increased pollution and nutrient inputs, habitat degradation including dredging, resource harvesting, and the regulation of water flows. All of these reasons are possible explanations for increasing HABs, and one or any combination of them may apply to a particular species.

Photo 7. Improved methods of detection have helped scientists determine that harmful algal blooms occur over a greater area in some parts of the country than was previously observed.

Improved Methods of Detection and Greater Monitoring Efforts. Outbreaks of paralytic shellfish poisoning caused by species of *Alexandrium* have occurred in the Northeast and Pacific Northwest for hundreds of years. Scientists do not believe that their frequency has increased, but rather, that the extent of these outbreaks occurs over a greater area than previously recorded (Boesch et al. 1996). Similarly, there is no evidence of an increased frequency of *G. breve* blooms in Florida, but the blooms seem to be more extensive and last longer (Boesch et al. 1996). On the other hand, HABs are being recorded today in coastal areas that had not experienced the problem two decades ago. For instance, North Carolina, Louisiana, Mississippi, and Alabama have all recently experienced *G. breve* blooms (Tester et al. 1991, Dortch et al. 1998). In addition, brown tides, caused by *Aureococcus anophagefferens* and *Aureoumbra lagunensis,* have become recurrent problems along the coast of Long Island and in the Laguna Madre of Texas within the last 15 years (Cosper et al. 1987, Buskey and Stockwell 1993). Finally, outbreaks of amnesic shellfish poisoning have only been known to science since 1987 (Bates, 1998). Recently, domoic acid-induced mortalities in sea lions and possibly birds and sea otters have plagued Southern California waters in the summer of 1998 and late spring of 1999 otters (Scholin et al. in review).

Introduction of Exotic Species via Ballast Water Exchange and Aquaculture. Currently, there is some evidence that ballast water may have introduced harmful algal blooms into Australian waters (Hallegraeff 1993), although recent information suggests that more local populations from Australian waters may be the actual source material for the blooms (Bolch et al. 1998). Ballast delivery has not been definitely shown in the United States (Boesch et al. 1996). Although circumstantial evidence suggests that HABs may have been introduced in the United States, current methods cannot determine when the dispersal occurred (i.e., over a few years versus millions of years) (Scholin and Anderson 1993). Genetically similar populations of several HAB species exist both in the United States and in other parts of the world, indicating that a dispersal has occurred, but the time and mode remain to be determined (Scholin and Anderson 1993).

(top)

Failure of Control by Grazers. Grazers' ability to regulate an algae population depends on timing as well as biological, chemical, and physical factors. Interactions between grazers (zooplankton in the case of phytoplankton, and larger crustaceans and mammals in the case of macroalgae) and HAB species appear to be specific. Apparently, toxins do not affect all consumers. Some zooplankton are able to eat the toxic algae without any effects, while other grazing zooplankton experience decreases in motility or fecundity, or die (Turner and Tester 1997). For example, *Brachionus plicatilis,* a rotifer, can feed on *Pfiesteria piscicida* without any deleterious effects (Burkholder and Glasgow 1995), but exhibits reduced feeding when *Heterosigma carterae* is ingested (Chotiyaputta and Hirayama 1978). In the case of another HAB (*Aureococcus anophageefferens*), it has been proposed that reduced grazing by protozoa resulted in the 1985 brown tide in Narragansett Bay (Smayda and Villareal 1989). The suite of results indicate that grazing losses are HAB-specific, leading to poor elucidation of the importance of grazing control in most areas (Turner and Tester 1997).

Human Activities. Strong relationships appear to exist between several algal groups and nutrient enrichment in certain localities. These few observations have resulted, perhaps erroneously, in a refrain that coastal eutrophication is responsible for global increases in HABs. The two algal groups that appear to bloom in response to increasing nutrient loadings include cyanobacteria (formerly known as blue-green algae) (Anderson et al. 1995) and macroalgae (Valiela et al. 1997). Nutrients may also be responsible for the proliferation of specific species. Higher densities of the nontoxic life stages of *Pfiesteria piscicida* have been reported in nutrient-rich waters resulting from hog farm overflows and sewage discharge, as well as from growth stimulation in laboratory cultures enriched with nitrogen or phosphorus (Burkholder and Glasgow 1997). In the North Sea, *Phaeocystis* may be increasing because both nitrogen and phosphorus inputs are on the rise, while silicon inputs remain low, the latter limiting the duration of a typical diatom bloom, leaving the excess nitrogen and phosphorus available for the *Phaeocystis* population (Lancelot et al. 1987). Localized nutrient enrichment resulting from human activities has resulted in serious HAB problems for two locales in Asia, the Seto Inland Sea in Japan (Okaichi 1989) and Hong Kong Harbor (Lam and Ho 1989), now considered the "classic examples" of human-induced HAB proliferation. Finally, river discharge and enhanced nutrient enrichment availability have been suggested as potential reasons for both past and recent blooms of toxic *Pseudo-nitzschia,* leading to amnesic shellfish poisoning and fatalities in mammals, including people (Smith et al. 1990; Scholin et al. in review).

Prevention, Control, and Mitigation

Because of the large impacts of coastal HABs, the control and prevention of problem species are of major interest to many groups. Control, mitigation, and prevention, however, are not straightforward matters, due to the complexities and current knowledge of bloom dynamics and the secondary effects that arise from intervention procedures. Federal and state agencies are working closely with local governments, academic institutions, and nonprofit groups to mitigate the effects of HABs and to develop prevention technologies for the future. Current research focuses on (1) identifying toxins, (2) developing routine tests for field monitoring of the nutritional and life-cycle characteristics of HAB species, (3) developing rapid and inexpensive tests for detecting the presence of HABs in coastal waters, (4) evaluation of specific flocculation procedures to strip HABs from coastal waters, and (5) isolation and characterization of natural viral and bacterial populations that might be used in biological control of HABs. Water-quality monitoring programs are accumulating baseline data about the status of water quality preceding and coincident with harmful algal blooms. These data will prove useful in the future development of HAB forecasting capabilities and predictive models. Information is widely available to the public from federal and state agencies, Web sites, and the National Office of Marine Toxins and Harmful Algae at Woods Hole Oceanographic Institute.
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HARMFUL ALGAL BLOOMS

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REGIONAL CONTRASTS

Harmful algal blooms occur in all coastal regions of the United States. Figures 4-7 illustrate the general distribution of HABs that result in known diseases. Although many of the same algae species appear in different regions, bloom conditions are not necessarily similar, nor are they fully understood. While the same species cause the same types of HAB problems in different regions, they may affect different organisms. Table 1, and the region-by-region discussion that follows, demonstrate the diversity of HABs in U.S. coastal areas.

Northeast

The chief HAB in the Northeast, *Alexandrium tamarense,* is responsible for annual outbreaks of paralytic shellfish poisoning. *Alexandrium* cells are entrained in two coastal currents in the region. One of these currents flows to the southwest, coinciding with river outflows in late May and early June, and creating an annual north-to-south toxicity pattern. In addition, dynamics of the currents and river-generated plumes are highly influenced by freshwater inflow, wind, and depth, which strongly govern the distribution of toxic cells and, therefore, their impacts.

Northeast and Mid-Atlantic

From the Northeast through the Mid-Atlantic region, specifically in lagoonal systems of eastern Long Island, New Jersey, Delaware, and Maryland, brown tide is a recurring HAB problem. The first recorded outbreak was in 1985 in Long Island. Several have occurred since then, the most recent along Maryland's Eastern shore in 1999. Impacts include the loss of submerged aquatic vegetation and the collapse of several shellfisheries, such as the bay scallops of eastern Long Island. The outbreaks occur from late spring to early summer and last from one to four months.

Another HAB group common to the Mid-Atlantic region is *Pfiesteria piscicida* and similar-looking cells known as *Pfiesteria* -complex organisms. In many environments, *P. piscicida* and *P.* -complex organisms have co-occurred with high numbers of fish with epidermal lesions, which, over time, may cause death due to secondary infections. Further, some evidence suggests that the fish secretions that accumulate in dense fish aggregations induce toxicity in some life stages of *P. piscicida,* resulting in the production of two toxic "fractions," one that is neurotoxic to the surrounding fish, and one that is dermonecrotic (i.e., causes the skin to slough and die). This combination of toxins from *P. piscicida* and the secondary infections resulting from pathogenic bacteria, fungi, and protozoa is probably responsible for the recent fish kills in several systems of Maryland's Eastern Shore and in coastal North Carolina.

(top)

The mechanisms responsible for the expression of *Pfiesteria* -related health problems in fish are not yet understood, although increasing information points to the importance of inorganic and organic nutrient enrichment as favorable growth conditions for the troublesome organism. Burkholder and Glasgow (1997) documented increasing numbers of nontoxic *P. piscicida* cells in hog-pond effluents and waters immediately downstream of sewage treatment discharge, as well as elevated cell numbers in cultures enriched with inorganic and organic nitrogen and phosphorus. Magnien et al. (1998) have suggested that the coincidence of several factors could explain the *Pfiesteria* -associated fish kills along

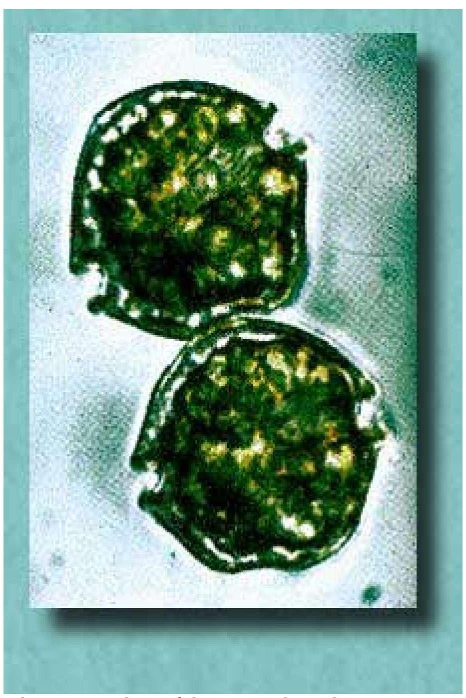

Photo 8. Members of the genus *Alexandrium*

are responsible for outbreaks of paralytic shellfish poisoning in the Northeast and the Northwest.

Maryland's Eastern Shore in the late summer of 1997. These include resident low levels of *P. piscicida,* long residence times of nutrient-rich waters in shallow, chlorophyll-rich brackish waters of poorly flushed river mouths, and high densities of coastal menhaden. If these same factors were to coincide in other systems, they might be explored as potentially responsible agents for recurrent fish kills and other health problems in the Mid- and South Atlantic regions.

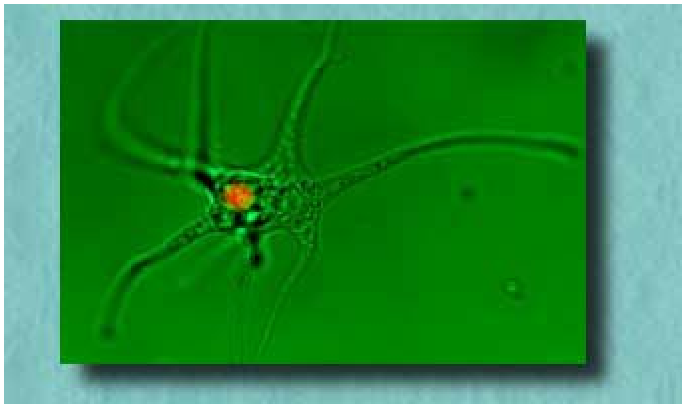

Photo 9. The amoeboid stage of *Pfiesteria piscicida* shown here has been magnified several hundred times.

Southeast

Southeastern states experience the same problems with *Pfiesteria* blooms as those in the Mid-Atlantic. In 1995 and 1996, the deaths of thousands, and in a single incident, millions, of fish from the coastal waters of North Carolina were attributed to *Pfiesteria* or *Pfiesteria* -like species (Burkholder and Glasgow 1997). Another HAB that has had an impact on southeastern states is *Gymnodinium breve,* which produces the toxin responsible for neurotoxic shellfish poisoning (NSP). Blooms are usually seasonal, starting in the late summer to early fall and lasting about three to four months. They appear to derive from offshore Gulf of Mexico populations, to increase over the west Florida shelf, and may later be transported to the South Atlantic Bight via the Loop Current and the Gulf Stream (Tester and Steidinger 1997).

Gulf of Mexico

In the Gulf of Mexico, the major HAB problems are brown tides and outbreaks of NSP caused by *G. breve.* In the Laguna Madre system of Texas, a dense bloom of the brown tide species *Aureoumbra lagunensis* persisted for more than seven years after its appearance in 1990 (Buskey et al. 1997). The bloom may have resulted from an unusual weather event during which subfreezing temperatures caused a massive fish kill, which, in turn, provided a pulse of nutrients to the hypersaline lagoonal waters. Additionally, resident grazer populations (e.g., microzooplankton, benthic organisms) were low prior to the bloom, suggesting that grazing losses may have allowed the initial development of *A. lagunensis.* The only demonstrable impact from the 7-year event was a loss of submerged aquatic vegetation in the deeper depths of the lagoon, due to light attenuation (Dunton 1994, Onuf 1996); fish densities remained the same.

The term "red tide" is now part of the common language and is associated with *G. breve* blooms that have occurred along Florida's western shelf since the 1950s. These blooms have been recorded since the Spanish explorations of the late 16th century, and have been reported in 23 of the last 24 years. The organism produces brevetoxin, which is the cause of neurotoxic shellfish poisoning in people and other mammals. This toxin causes huge problems nearly every year, including fish and mammal mortalities and mass closures of shellfish beds from Florida through Texas. A bloom of *G. breve* just south of Tampa Bay killed more than 150 manatees in 1996, and another killed more than 21 million fish along the Texas coast in 1997-1998. Some single events have been estimated to cost $20 million in lost revenues. People can become ill after eating affected shellfish, but more commonly, respiratory distress occurs in compromised individuals, such as older citizens and asthmatics, who have inhaled the toxin while in or near the water.

(top)

Pacific

On the Pacific Coast, paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and finfish mortalities from blooms of the *Heterosigma* and *Chaetoceros* species are major HAB problems. Outbreaks of PSP are recurrent, although the bloom dynamics are not well understood. Off the coast of California, the first major outbreak of ASP was reported in the summer of 1991. Since that time, domoic acid has been found in both autumn and spring plankton communities. In Monterey Bay, blooms of the domoic acid-producing diatom *Pseudo-nitzschia* are most common in the summer and autumn months, whereas in southern California, blooms are most common in the late spring to early summer. In late May through June 1998, the deaths of more than 50 sea lions, and illnesses in several other sea lions, birds, and sea otters, were attributed to domoic-acid poisoning caused by a bloom of the diatom *P. australis* off the coast of California near Santa Cruz (Scholin et al. in review). Although domoic acid was not detected in the tissues of many of the sea lions, it was found in the urine of several. Furthermore, investigating scientists from state, university, and federal labs detected high levels of domoic acid in sardines and anchovies, which are common foods of sea lions (Scholin et al. in review). Lesions of the hippocampus portion of the brain, characteristic of domoic-acid exposure in mammals, were also observed in several of the dead animals.

Off the coast of Washington, little is known about bloom dynamics for any of the HAB species, but parts of the coast have to be closed to bivalve harvesting on a year-round basis. Mass mortalities of penned fish have been recorded in fjords of the region, due to the flagellate *Heterosigma* and two diatom species of *Chaetoceros.* The former likely produces an ichthytoxin, while the spiny diatoms clog the gills of fish, leading to excessive mucus production and suffocation. In Alaska, recurrent blooms of the PSP-producing *Alexandrium* species -- also seen in the Gulf of Maine -- during nearly every month of the year has eliminated the development of any shellfishery, and has caused the deaths of several native people.

Tropical Regions

Ciguatera fish poisoning is a major problem in tropical regions, and may be the most widespread HAB-generated problem in the world. Caused by benthic dinoflagellates, toxicity results from bioaccumulation of the toxin in the food chain. An example can be seen in the benthic dinoflagellate *Gamberdiscus toxicus*. The dinoflagellate does not form blooms in the water column, but lives on the surface of red and brown macroalgae associated with coral reefs. Herbivorous fish that eat the macroalgae are eaten by larger fish and so on, until the toxin accumulates in the tissues of top-predator species that are often the primary foods of local island inhabitants.

Regional Summary

In conclusion, harmful algal blooms of cyanobacteria, other phytoplankton, microphytobenthos, some protozoa, and macroalgae are affecting all U.S. coastal areas. Cyanobacteria and macroalgae are stimulated by excessive nutrient loading. Although these two HAB groups displace the existing flora, cyanobacterial blooms are highly sensitive to temperature shifts and low sunlight, which cause a bloom's rapid demise. On the other hand, macroalgal blooms are more persistent, and may actually replace seagrass beds and coral reef systems over the long term.

Photo 10. A bloom of cyanobacteria, formerly known as blue-green algae, colors this section of the Potomac River bright green.

(top)

STATE OF THE COASTAL ENVIRONMENT

HARMFUL ALGAL BLOOMS

CASE STUDIES

The following are descriptions of two algal genera that form harmful blooms. One of these species, *Gymnodinium breve,* is typical of the Gulf Coast, while the other, *Pseudo-nitszchia* sp.*,* was only recently linked to harmful blooms on the West Coast. *G. breve* has been intensively investigated for several decades, while information about toxic *Pseudo-nitzschia* only began to appear in 1987.

Gymnodinium breve

Gymnodinium breve, unlike some of the other HAB species, has been well documented in maritime and coastal history, especially in the Gulf of Mexico region. The earliest recorded fish kill, later attributed to a *G. breve* bloom, was in 1844 off the west coast of Florida. Since that time, recurrent outbreaks have characterized the west Florida and Texas coasts. In the late 1940s, scientists noticed a number of linkages associated with this toxic species and derived primarily from effects produced by the bloom. High cell densities of this toxic dinoflagellate discolor surface waters with a typical red coloration, producing what has commonly been referred to as "red tide." However, prior to actually seeing a "red tide," beach-goers may experience respiratory problems because cells and released toxins are inhaled as an aerosol. The toxic aerosol can affect humans at much lower concentrations than are required for the human eye to actually see discoloration in the water. *G. breve* produces brevetoxin, which is lethal to fish and results in massive fish kills that wash up and decompose on local beaches. Fish kills can occur before the water is visibly discolored, at concentrations of ~0.5 million cells per liter. Exposure to brevetoxin can also cause marine mammal mortalities; in 1996, more than 150 manatees were killed just south of Tampa Bay.

Within the Gulf of Mexico region, these blooms are considered a natural phenomenon, and have not been attributed to any human factors. It appears that *G. breve* bloom dynamics are most closely coupled to physical processes (Tester and Steidinger 1997). A resident population exists in the Gulf of Mexico at all times, with background concentrations of 1 to 1,000 cells per liter. Bloom initiation, transport, and retention are all strongly affected by the extent of the northward penetration of an offshore, clockwise current known as the Loop Current, its spinoff eddies, and its intrusions onto the west Florida shelf. Blooms may originate around the fronts caused by the flow of the Loop Current along the outer southwest Florida shelf, approximately 40 to 80 miles offshore (Mote Marine Laboratory 1998 on-line, Tester and Steidinger 1997). These fronts are characterized by various nutrient (organic and inorganic) and light regimes conducive to the growth of *G. breve* (Steidinger et al. 1998).

Once growth of the algae has been initiated, it may take up to 8 weeks for the cells (and toxins) to develop in concentrations high enough to kill fish (Tester and Steidinger 1997). *G. breve* blooms are some of the largest recorded, spanning areas of hundreds to thousands of square miles. For example, a bloom off the coast of Florida in 1964 covered an area of 14,000 square kilometers, from Apalachee Bay to Piney Point. The timing of *G. breve* blooms along Florida's western coast is well known, with occurrences possible throughout the year but most probable in late summer and fall (Tester and Steidinger 1997). The persistence of a bloom depends on physical, biological, and chemical conditions and can range from a few months to more than a year; the longest bloom ever recorded began in September 1994 and ended in April 1996 in an area from Tarpon Springs to the Florida Keys (Mote Marine Lab 1998 on-line). Blooms are more frequent along the west coast of Florida, which has reported blooms during 23 of the last 24 years, than along the coast of Texas, which has

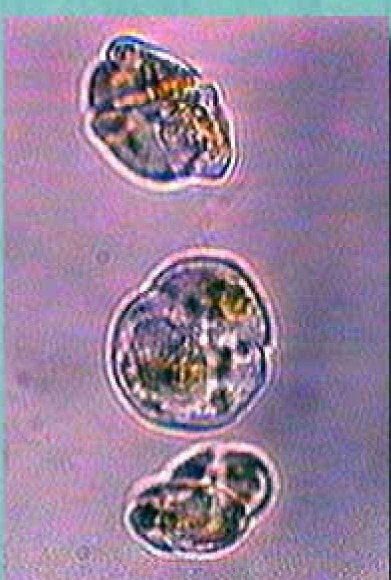

Photo 11. The *Gymnodinium breve* cells shown here have been magnified 400 times. Blooms of *G. breve* are some of the largest ever recorded. In the Gulf of Mexico, they appear to occur

In the Gulf of Mexico, they appear to occur naturally and have not been attributed to any human activities or influences.

experienced only three major blooms, in 1935, 1986, and 1997-1998 (Pinkerton 1998).

The results of these blooms can be both physically and economically devastating to a region. In April 1963, a bloom that occurred from Tampa Bay to Marco Island resulted in the deaths of more than 150 tons of fish, including a 700-pound grouper (Mote Marine Lab 1998 on-line). The red tide off the coast of Texas and Mexico between October 1997 and January 1998 was responsible for killing more than 14 million fish (Pinkerton 1998); the estimate was later increased to 21 million. These incidents and others like them have had severe impacts on several industries, including fisheries (fish and shellfish) and tourism. Blooms have also affected several other wildlife species, including manatees and birds. Besides the 1996 bloom that killed the manatees, a bloom in the Caloosahatchee River area of Florida in 1982 resulted in the deaths of 39 manatees (Landsberg and Steidinger 1998), illustrating the serious impact that these recurrent natural events can have on an endangered species. To emphasize this, a red tide now in progress (Fall 1999) off the coast of the Florida panhandle is believed to be responsible for more than 65 bottlenose dolphin mortalities since August 1999, when normally one or two are observed (Rowles 1999).

In Florida, there is strong community awareness and a commitment to reduce the impacts of these nearly annual events on the western coast. Researchers from academic, federal, state, and local organizations, as well as industry and citizen groups, all work to monitor and mitigate the potential effects of harmful algal blooms. Using remote sensing as well as sampling cruises, researchers have been able to chart the progression of a bloom from initiation to senescence. These observations are being used to develop a forecasting ability for the transport of offshore blooms into coastal regions (NOAA Coastal Services Center 1998). With this information, coastal communities will be able to proactively limit the potential impacts of landfall of these toxic populations and the associated fish kills that are deposited on recreational beaches.

Pseudo-nitzschia **spp.**

Pseudo-nitzschia is a long, slender diatom that may produce domoic acid, the toxin responsible for amnesic shellfish poisoning (ASP). Members of this diatom genus were first identified as a toxic HAB species in 1987 in Prince Edward Island, Canada, when 150 people became ill and three died as a result of eating blue mussels, rich in domoic acid, that had been harvested locally from Cardigan Bay. In 1988, researchers grew cultures of the diatom in the lab and measured the production of domoic acid, thereby making a connection between the toxin found in the poisoned mussels and a *Pseudo-nitzschia multiseries* bloom that occurred in the Cardigan River at the same time (Wright et al. 1989). As a direct result of this research, Canada began an intense monitoring program to decrease the harmful effects of *Pseudo-nitzschia,* and provided the global community with important information for safeguarding public health.

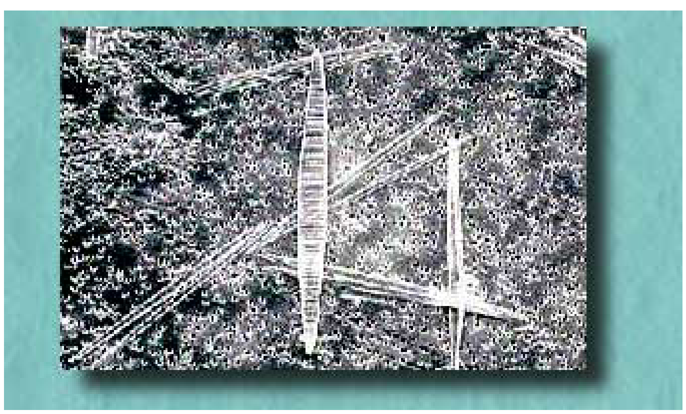

Photo 12. Blooms of *Pseudo-nitzschia* produce domoic acid, a gastrointestinal and neurological poison that causes amnesic shellfish poisoning and can be lethal. Because the diatoms do not change the color of seawater, they are difficult to detect.

While *Pseudo-nitzschia* blooms and domoic acid have been considered potential threats to New England waters since the event in Prince Edward Island in 1987, they were not observed in the United States prior to 1991, when they appeared on the West Coast. In September 1991, domoic acid was identified as the causative agent for the deaths of brown pelicans and cormorants in Monterey Bay, California (Work et al., 1993), and in November, the toxin was detected in razor clams harvested along the

Oregon and Washington coasts. After the shellfish beds were closed to harvesting, domoic acid was detected in dungeness crabs, leading to harvest closures for this species. Similarly high levels of domoic acid, simultaneous to a bloom of *Pseudo-nitzschia pungens, P. multiseries,* and *P. australis,* were noted in 1994 in mussels sampled from Hood Canal, Washington (Horner et al. 1997). Poisonings are also highly probable for coastal Alaskan waters because potentially toxic *Pseudo-nitzschia spp.* have been identified and are fairly common in the region (Horner et al. 1997).

Photo 13. Shellfish that consume *Pseudo-nitzschia,* such as these mussels, can accumulate domoic acid in their viscera and flesh. In turn, the birds, mammals, and people that eat them may fall ill with amnesic shellfish poisoning (ASP). Some human victims never fully recover from the short-term memory loss that is a classic symptom of ASP.

A recent outbreak of domoic-acid poisoning occurred in May 1998, when many apparently well fed sea lions washed ashore along the coast of California from San Luis Obispo to Santa Cruz (Northwest Fisheries Science Center 1998 on-line). The animals exhibited signs of physical distress, including frothing at the mouth, violent seizures, and vomiting. By the end of June, more than 40 of the sick animals had died. Postmortem analyses revealed microscopic lesions in the hippocampus region of the brain, previously identified as characteristic of domoic-acid poisoning; domoic acid was also detected in the urine of some of the affected animals. The incident has been postulated to be the result of a *Pseudo-nitzschia australis* bloom that was first observed off Santa Cruz on May 11, 1998 (NWFSC 1998 on-line).

Using regular cruises for monitoring and sampling, scientists are attempting to understand the environmental, chemical, and physical factors that trigger the accumulation of the domoic acid-producing species, as well as the factors that induce their toxicity. To date, five species found on the U.S. West Coast have been shown to produce domoic acid: *P. multiseries, P. australis, P. pseudodelicatissima, P. pungens,* and *P. seriata* (Horner et al. 1997). To the dismay of coastal managers everywhere, these species have global distributions, and pose potentially deadly threats to coastal living resources and the people who live, work, and recreate in coastal regions.

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HARMFUL ALGAL BLOOMS

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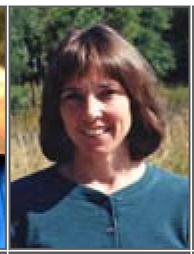
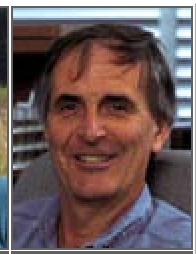
EXPERT INTERPRETATION

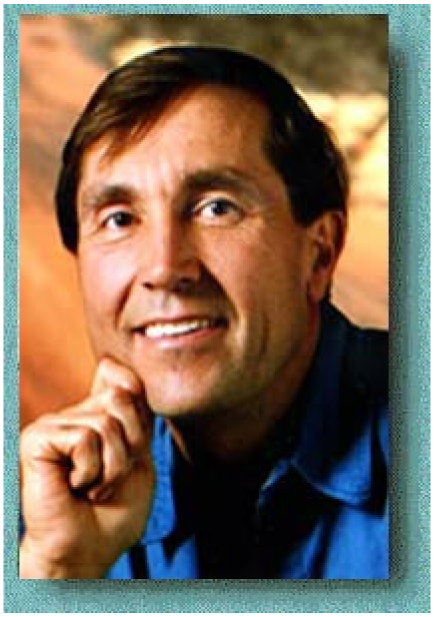
The three individuals below are experts in the topic of harmful algal blooms. Here they voice their opinions on two questions relevant to that topic.

Question 1. Are there significant linkages between land-based activities and harmful algal blooms?

Question 2. Are there strategies to control, mitigate, and ultimately eliminate the outbreaks and health impacts of harmful algal blooms?

Experts

		
Donald M. Anderson	**Fran Van Dolah**	**Jonathan Sharp**



Donald M. Anderson

Senior Scientist, Biology Department, Woods Hole Oceanographic Institution

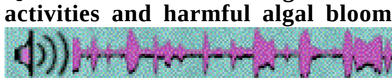
Since the late 1970s, Dr. Anderson has been studying the physiology and genetic regulation of toxicity in dinoflagellates, their bloom dynamics and ecology, and the global biogeography of toxic *Alexandrium* species. He is heavily involved in national and international program development for research and training on red tides, marine biotoxins, and harmful algae. He serves as the Director of the U.S. National Office for Marine Biotoxins and Harmful Algae, located at the Woods Hole Oceanographic Institution.

Response to Question 1

Response to Question 2

(top)

Question 1. Are there significant linkages between land-based activities and harmful algal blooms?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There are some very clear linkages between land-based activities and harmful algal blooms (HABs). Many HABs occur in relatively pristine waters, and show no influence from pollution or other human activities. On the other hand, some of these phenomena show strong linkages to activities such as pollution, which provides nitrogen and phosphorus to the algal cells which use these nutrients to become more abundant. HAB scientists generally accept that enrichment of coastal waters results in an enhancement of many algal species, only some of which are harmful or toxic. The most recent example of the linkage between pollution and a HAB event is with the *Pfiesteria* outbreaks in North Carolina and Maryland, where the causative species is found predominantly in areas receiving runoff from hog and chicken farms. Other human activities which have been linked to HABs include ballast water introduction of species as a result of international shipping. Another example is aquaculture, which tends to put farmed fisheries resources in locations which then become the sites of HAB outbreaks--either because those resources are carefully monitored for toxins, or because, in some instances, the aquaculture facilities enrich the surrounding waters with nutrients through over-feeding and waste that then stimulate HABs.
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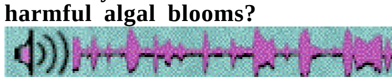
Question 2. Are there strategies to control, mitigate, and ultimately eliminate the outbreaks and health impacts of harmful algal blooms?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There are a number of strategies that are either used, or are under investigation that can reduce the impacts from harmful algal blooms (HABs). Some of these are practical and widely accepted, while other are highly controversial and untested. An example of the former would be the routine monitoring programs for toxins in shellfish that keep dangerous products off the market. Another would be strategies to tow fish (aquaculture) cages out of the path of approaching toxic blooms. Long-term mitigation strategies include the reduction of pollution inputs to coastal waters, one effect of which is likely to be a reduction in the number and severity of HAB outbreaks. A more controversial approach to mitigation involves efforts to directly intervene in the bloom process-i.e., to target the HAB organism itself. This approach is quite common on land in the fight against terrestrial pests, but is seldom used in the ocean against "marine pests" because of concerns about environmental impacts. Nevertheless, scientists are now exploring direct control strategies along several lines. One is biological control, whereby bacteria, viruses, parasites, and other pathogens might be used to control a particular HAB species. Another approach involves the use of chemicals or natural materials such as clays which can alter the abundance of cells in a HAB population. This area of HAB research is in its infancy.
(top)

Fran Van Dolah

Research Biochemist, Center for Coastal Environmental Health and Biomolecular Research, National Ocean Service, NOAA

Dr. Van Dolah has been with NOAA's Marine Biotoxins Program for eight years, where her research has focused in two areas. First is the development of rapid assays for a variety of marine biotoxins in seawater, algae, seafood, and marine mammals. The second is research on cellular and molecular mechanisms regulating growth and cell division in toxic dinoflagellates.

Response to Question 1

Response to Question 2

(top)

Question 1. Are there significant linkages between land based activities and harmful algal blooms?

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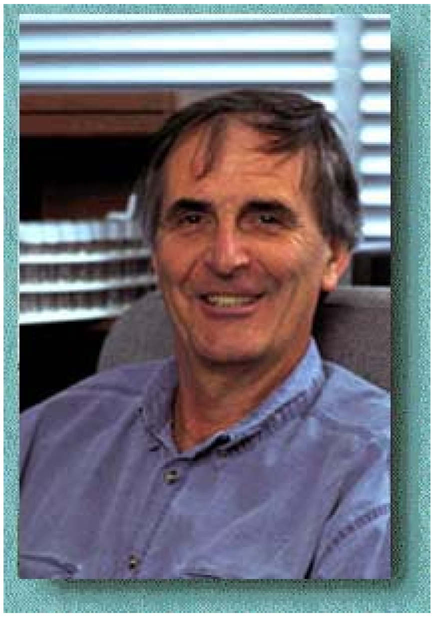
Anthropogenic impacts on coastal waters do appear in some instances to contribute to the occurrence of algal blooms. However, the diversity of organisms collectively termed "harmful algae", and the diversity of life history strategies these organisms have evolved, make broad generalizations inappropriate. For example, blooms of two of the most problematic dinoflagellates in U.S. coastal waters, *Alexandrium spp.* , responsible for paralytic shellfish poisoning on the northeast and west coasts, and *Gymnodinium breve* , responsible for neurotoxic shellfish poisoning in the Gulf of Mexico, initiate offshore in oligotrophic waters. These species are well adapted for growth in low nutrient conditions and there is no compelling evidence to suggest that nutrient input into coastal waters contributes to their bloom formation. However, in other cases increased nutrient loading clearly does correlate with increases in the incidence of HABs. Between 1965 and 1976, a 6-fold increase in the population of Hong Kong was accompanied by a 2.5-fold increase in nutrient loading and an 8-fold increase in the frequency of HABs. Agricultural runoff of phosphorus is known to stimulate cyanobacterial blooms. However, a more complex picture is emerging which suggests that changes in chemical forms of nutrients and nutrient ratios may be equally important as total nutrient loading in coastal waters. Increases in phosphate, for example, may result in silica-limited conditions that favor nuisance flagellates over diatoms. Coastal development may also cause shifts in phytoplankton communities by altering concentrations of natural organic chelators present in drainage from forested areas, as these areas become urbanized or cleared for agricultural use.
(top)

Question 2. Are there strategies to control, mitigate, and ultimately eliminate the outbreaks and health impacts of harmful algal blooms?

Click here for audio response

Harmful algal blooms are currently not managed sufficiently. Management options include prevention, control, and mitigation. Prevention is directed at minimizing anthropogenic impacts that may contribute to bloom formation. Legislated reductions in chemical and nutrient inputs, for example, have successfully reduced algal growth in certain cases. However, these strategies do not address all HABs, including those that initiate offshore. Control strategies include chemical or biological agents that target a bloom, once initiated. These are not currently employed in the U.S., and have been approached with caution for a number of reasons. Most important is the potential for adverse effects such strategies may have on coastal ecosystems. We currently lack sufficient insight into mechanisms regulating blooms of any HAB species to implement effective species-specific controls. In the case of dinoflagellates which historically form episodic blooms, it is not clear that control of blooms is even desirable, since the role these blooms play in their respective ecosystems is not known. Thus, while control strategies may hold great potential, insight into the ecophysiology of HAB species is necessary to support their design and rigorous testing for adverse effects is essential prior to implementation. Mitigation encompasses diverse efforts to minimize HAB impacts, and is currently the major management strategy employed. Among these, shellfish and phytoplankton monitoring programs have been highly successful in protecting public health. A promising new approach, to which significant research is currently directed, is development of forecasting capabilities. Forecasting holds promise as a strategy to mitigate economic and environmental impacts of HABs.

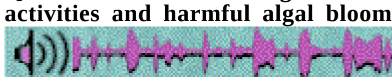


Jonathan Sharp

Professor, The Graduate College of Marine Studies, University of Delaware

Professor Sharp joined the faculty of the University of Delaware in 1973. For the past 25 years, he has conducted fieldwork primarily in mid-Atlantic coastal waters and in the Delaware Estuary. His research emphasis is in biogeochemical studies of the dynamics of plant nutrients, dissolved and particulate organic matter, and microbial (phytoplankton and bacteria) interactions. He also conducts research in measuring dissolved organic carbon and nitrogen in the ocean. Professor Sharp served as Chair of the Scientific and Technical Advisory Committee for the Delaware Estuary Program and currently is Vice-chairman of the Board of Directors of the non-profit Partnership for the Delaware Estuary.

Question 1. Are there significant linkages between land based activities and harmful algal blooms?

Click here for audio response

My answer is a qualified "No". There is evidence of massive harmful algal blooms (HABs) occurring long before human land-based activities altered the coastal oceans. In addition, the HABs often occur slightly distant from the areas of maximum land-based inputs. While there are suggestions that the frequency and intensity of HABs have increased in recent years, these are based on circumstantial evidence, not on significant causal evidence. On the other hand, land-based activities have increased loadings to estuaries and coastal oceans of nutrients and other excess materials from agricultural, industrial, and municipal activities. Human activities have also greatly altered the physical nature of estuarine and coastal habitats. As a consequence, the chemical composition of the coastal environment has been changed. Since inputs have greatly increased concentrations of nitrogen and phosphorus nutrients, there is reason to expect associations between nutrients and algal populations. However, we must recognize that there are changes not only in overall concentrations, but also in ratios of nitrogen to phosphorus, to silicon, and to numerous trace elements. In addition, trace metal and organic chemical compounds serve as contaminants with potential negative impacts on coastal ecosystems. Overall, the chemistry of nearshore ocean waters has changed from land-based activities and these changes probably contribute to ecosystem nature and function being altered. However, we do not sufficiently understand the complex ecosystem responses (including algal growth, species changes, and food web transfer) to link inputs from land-based activities to specific responses, such as HABs.
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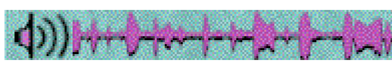
Question 2. Are there strategies to control, mitigate, and ultimately eliminate the outbreaks and health impacts of harmful algal blooms?

Click here for audio response

I am aware of some actions have been taken to minimize health impacts of HABs that appear to be appropriate. However, I do not feel that adequate strategies to control, mitigate, and eliminate outbreaks are in place. It is not feasible to develop accurate strategies for a problem when the problem is inadequately described. Far more attention must be addressed on why HAB outbreaks do not occur in some areas when they do in others. For many years, we have recognized HAB problems, including numerous human deaths; but we have dedicated very little research to understanding HABs. Recently, public and political concern has directed some funding toward HAB monitoring, research, and mitigation. Much of this concern has been stimulated by publicity on *Pfiesteria* , a relatively minor HAB problem. Unfortunately, some of the monitoring and most of the mitigation is predicated on the assumption that we understand more about the problem than we actually do. Also, emphasis on *Pfiesteria* has been disproportionate when compared to other HAB problems. A main target has been nutrient runoff controls. In attempts to control nutrient runoff, we will also control other chemical runoff into estuarine and coastal waters and this may be a beneficial action. However, if a specific nutrient (i.e., nitrogen or phosphorus) is not the specific cause of a HAB outbreak, unrealistic expectations will be made for the impact from such controls. If we really wish to control HABs, we must invest more funding in research that is not constrained by preconceived ideas.
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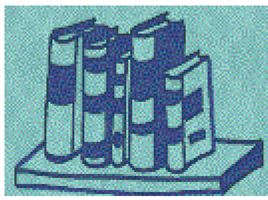

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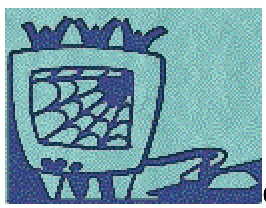

On-line References

The following references were accessed via URL on the World Wide Web during 1998 and 1999.

Note: Harmful algal blooms (HABs) are a topic of national concern. The Web references presented here are intended to provide supplementary information related to the text of this essay. These references also supply links to many additional sites.

Algal Species

Alg@line Data Base.

http://meri.fimr.fi/Algaline/eng/EnAlgaline.nsf?OpenDatabase

Includes a database of harmful algal blooms in the Baltic, Bothnian, Åland, and Archipelago seas and the Gulf of Finland along with a photo gallery of hundreds of species of phytoplankton. The Web site is produced in cooperation with various Finnish and Estonian research and scientific institutes.

Congressional Research Service. Pfiesteria and related harmful blooms: Natural resource and human health concerns.

http://www.cnie.org/nle/mar-23.html#Federal Response

Provides detailed information on what *Pfiesteria* is, water quality conditions related to blooms, interactions with the environment, and effects on human health and living aquatic resources. Also discusses state and federal agencies' responses to the problem.

Florida Marine Research Institute. ECOHAB: Florida. HAB species.

http://www.fmri.usf.edu/ecohab/subsalsa.htm

Discusses in detail eight separate algal species, including information about distribution, habitat, toxins, ecological impacts, impacts on animals, human health, and associated types of shellfish poisoning.

North Carolina State University. Aquatic Botany Laboratory, *Pfiesteria piscicida* page.

http://www2.ncsu.edu/unity/lockers/project/aquatic_botany/pfiest.html

Provides detailed information on *Pfiesteria piscicida,* including life cycle, effects on fish and shellfish, and impacts on human health.

University of Calgary. Dinoflagellates.

http://www.geo.ucalgary.ca/~macrae/palynology/dinoflagellates/dinoflagellates.html

Provides general information on several dinoflagellate species, including basic anatomy; includes diagrams and scanning electron microscope images.

University of California at Berkley. Introduction to the Bacillariophyta (diatoms).

http://www.ucmp.berkeley.edu/chromista/bacillariophyta.html

Provides detailed information on the life history, ecology, morphology, and systematics of the diatoms.

University of California at Berkley. Introduction to the Dinoflagellata.

http://www.ucmp.berkeley.edu/protista/dinoflagellata.html

Provides detailed information on the life history, ecology, morphology, and systematics of the dinoflagellates.

Woods Hole Oceanographic Institution. Species responsible for harmful algal blooms.

http://habserv1.whoi.edu/hab/species/species.html

Briefly describes various HAB species; includes detailed photos.

Bloom Detection.

National Aeronautics and Space Administration. Plankton blooms: The good, the bad, and the shiny.

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/classic_scenes/12_classics_blooms.html

Contains general information on detecting blooms using ocean color data from the Coastal Zone Color Scanner satellite.

Region-specific Information

National Marine Fisheries Service, Northwest Fisheries Science Center. Harmful algal bloom and marine biotoxin pages.

http://www.nwfsc.noaa.gov/hab/

Provides information on HAB biology, including the mechanisms that cause them to spread, toxin detection, and protection of public health. HAB issues for the West Coast and Alaska are highlighted, with details on paralytic shellfish poisoning, domoic acid poisoning, heterosigma problems, and diarrheic shellfish poisoning. Also includes an on-line version of *The West Coast Marine Biotoxin and Harmful Algal Bloom Newsletter*.

Mote Marine Laboratory. About red tide.

http://www.marinelab.sarasota.fl.us/~mhenry/rtchrono.phtml

Offers information about red tide in Florida, including updates on current blooms and closed shellfish areas. Also includes a historical chronology of red tide along Florida's Gulf Coast.

Texas Parks and Wildlife. Frequently asked questions about red tide.

http://www.tpwd.state.tx.us/fish/recreat/redtide.htm

Offers general information on red tide in Texas, including information on *Gymnodinium breve* blooms and associated shellfish-area closures.

Woods Hole Oceanographic Institution. ECOHAB: Gulf of Maine.

http://crusty.er.usgs.gov/ecohab/

Offers information about HABs in the Gulf of Maine, including data and the locations of toxicity monitoring stations.

Status and Trends

Anderson, D.M.1995. Toxic red tides and HABs, a practical challenge in coastal oceanography. U.S. national report to IUGG, 1991-1994. Review of Geophysics, vol. 33 supplement, American Geophysical Union.

http://www.agu.org/revgeophys/anders01/anders01.html

Discusses recent trends, causative factors, nutrient dynamics, emerging technologies, and management and policy issues. Includes an extensive bibliography of published literature.

U.S. Environmental Protection Agency. National harmful algal bloom research and monitoring strategy: An initial focus on *Pfiesteria,* fish lesions, fish kills and public health.

http://www.epa.gov/nep/pfiesteria/fish2.html

Describes federal agencies' efforts to develop and coordinate a long-term national strategy for federally supported research and monitoring on problems associated with HABs, particularly *Pfiesteria* and *Pfiesteria* -like species.

Woods Hole Oceanographic Institution. The harmful algae page.

http://habserv1.whoi.edu/hab/

Contains maps of current HAB locations and trends; provides information on HABs, including introductory material on what algal blooms are and how they form, characteristics of various harmful species, and the adverse impacts of blooms. Includes recent news coverage about current HAB outbreaks.

Toxins

Florida Marine Research Institute. ECOHAB: Florida. Seafood poisonings.

http://www.fmri.usf.edu/ecohab/poison.htm

Provides detailed information on the various toxins produced by HABs, the factors affecting toxicity, the symptoms and diagnosis of human illnesses, and the types of seafood that cause illness.

U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition. Various shellfish-associated toxins.

http://vm.cfsan.fda.gov/~mow/chap37.html

Briefly discusses shellfish-associated algal toxins, detection of toxicity in shellfish, the symptoms, effects and diagnosis of shellfish poisoning, and past outbreaks.
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Appendix A Known HAB Toxins and Effects

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Known HAB Toxins and Effects

Type of Poisoning	Symptoms	Course of Disease
Ciguatera Fish Poisoning (CFP) is caused by several different toxins, including ciguatoxin, scaritoxin, maitotoxin, and okadaic acid. Some of these toxins are known to be produced by the dinoflagellate *Gamberdiscus toxicus*, which is naturally found in subtropical and tropical regions and is eaten by herbivorous fish.	**Gastrointestinal**: diarrhea, vomiting, abdominal pain **Neurological**: headache, reversal of hot and cold sensations, vertigo, muscular weakness, numbness **Cardiovascular**: irregular heart rhythm, lowered blood pressure	There is no antidote for this type of poisoning. It is usually self-limiting and symptoms subside within several days, usually without lasting side effects. Initial signs of poisoning occur within six hours after ingestion.
Paralytic Shellfish Poisoning (PSP) is caused by more than 20 different saxitoxins, which are produced by members of the genus *Alexandrium*. Saxitoxins accumulate in shellfish (primarily mussels, clams, cockles, and scallops), which are filter feeders. In turn, people and animals may be affected after consuming the shellfish.	**Neurological**: respiratory paralysis, tingling, burning, numbness, drowsiness, incoherent speech, rash)	There is no antidote for PSP, which may be considered life threatening if the victim does not receive proper medical support. Recovery usually occurs within 24 hours of onset without lasting side effects. The onset of symptoms is rapid (one-half to two hours after ingestion) and depends on the amount of toxin consumed. Death can occur if the victim has consumed a large amount of the toxin and if respiratory paralysis occurs. With medical support, the victim usually recovers within 12 hours.
Diarrheic Shellfish Poisoning (DSP) is thought to be caused by several toxins, including yessotoxin, dinophysis toxins, pectenotoxins, and okadaic acid. Some of these toxins are known to be produced by *Dinophysis sp.*, which is filtered by shellfish (primarily oysters, scallops and mussels). DSP is prevalent in Europe and has been seen in eastern Canada; it has not been reported in the United States.	**Gastrointestinal**: nausea, vomiting, diarrhea, abdominal pain, chills, headache, fever	There is no antidote, but recovery normally occurs within three days of onset without lasting side effects. Onset is rapid, occurring one-half to two hours after ingestion.
Amnesic Shellfish Poisoning (ASP) is caused by domoic acid, which is produced by several members of the diatom genus *Pseudo-nitzschia*. Domoic acid accumulates in the animal's viscera; in some cases (e.g., razor clams), it also accumulates in the flesh.	**Gastrointestinal**: nausea, vomiting, abdominal cramps, diarrhea) **Neurological**: dizziness, headache, seizures, disorientation, short-term memory loss, respiratory difficulty, coma	There is no antidote, and the disease may be considered life threatening. The onset of gastrointestinal symptoms begins within 24 hours of ingestion, and neurological symptoms occur within 48 hours. In many cases, recovery from ASP is never complete, because many victims suffer short-term memory loss.
Neurotoxic Shellfish Poisoning (NSP) is caused by brevetoxins produced by the dinoflagellate *Gymnodinium breve*. It has been found to be associated with shellfish harvested along Florida and in the Gulf of Mexico.	**Gastrointestinal**: diarrhea, vomiting **Neurological**: tingling and numbness of lips, tongue, and throat, muscle aches, dizziness, reversal of hot and cold sensations	There is no antidote, but recovery normally occurs within hours to several days of onset with few aftereffects. Onset is rapid, occurring within minutes to a few hours after ingestion.
Cyanobacterial poisoning is caused by a variety of toxins, including microcystins and anatoxins. They are produced by different species of cyanobacteria, including *Anabaena sp., Aphanizomenon sp.,* and *Microcystis sp.*	**Neurological**: derangement, staggering, tremors **Hepatological**: induced liver failure, abdominal pain	There are no known antidotes for cyanobacterial poisoning. Currently, it is not known which dosages trigger certain responses (Carmichael 1997). Death may occur due to liver failure (Carmichael 1997).

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GLOSSARY

algae: a diverse group of chiefly aquatic plants (e.g., seaweed, pond scum, stonewort) that contain chlorophyll but lack roots, stems, leaves, and vascular tissues, and may passively drift, weakly swim, grow on a substrate, or take root in a water body.

anoxic: devoid of dissolved oxygen.

benthic: pertaining to organisms living in or on the bottom of aquatic environments (e.g., polychaetes, clams, snails).

biodiversity (species diversity): the variety of species found in a particular habitat.

cyanobacteria (also blue-green algae): bacteria that contain chlorophyll *a* (a pigment used for photosynthesis) and are able to photosynthesize.

diatom: any of numerous microscopic, one-celled, marine and freshwater algae having cell walls that contain silica; diatoms are a food source for all kinds of marine life.

dinoflagellates: an order of protozoans that are members of the order *Dinoflagellida.* They typically have two flagella, one that propels water to the rear and another that rotates the body. Some dinoflagellates can photosynthesize, while others are strictly heterotrophic.

domoic acid: a naturally occurring neurotoxic amino acid that can disrupt the transmission of impulses from cell to cell.

embayment (bay): an inlet of the sea or other water body, usually smaller than a gulf, that has reduced or restricted water exchange with the larger body of water to which it is connected.

flagellate: a cell or organism capable of motion through flagellar (whiplike) activity.

genetically similar populations: populations of organisms that contain DNA sequences that are similar to one another.

genus (pl. genera): one of the major taxonomic groups used to scientifically classify plants and animals. Several closely related species make up a genus; several genera make up a family.

grazer: organisms that eat primary producers (e.g., phytoplankton).

habitat: the living place or "home" of a particular organism or biological community.

heterotrophic: an organism capable of sustained growth on an organic substrate in the dark.

hypoxia: low concentrations of dissolved oxygen in the water, usually ranging between 0 and 2 milligrams per liter.

invertebrates: animals lacking a spinal column (e.g., crabs, lobsters, shrimp).

loop current: the dominant circulating water mass in the Gulf of Mexico, which enters through the Yucatan Strait (between the Yucatan Peninsula and Cuba) and extends northward, eastward, and then southward, where it exits through the Straits of Florida (between the Dry Tortugas and Cuba, where it is known as the Florida current). The loop current is known to extend far to the north and occasionally to intrude on the continental shelf of the north-central Gulf, at speeds of 127 to 177 centimeters per second. Large, clockwise-rotating portions of the loop current, called "eddies," occasionally break off from the main current. These eddies spin westward toward the Texas coast, carrying vast amounts of water and marine life into the western Gulf.

monitoring: periodic measurements of the same parameters, physical or biological, designed to detect changes over time.

nutrient enrichment: an increase in the amount of nutrients added to an ecosystem, above normal levels; pollution occurs when damaging amounts of nutrients are added.

nutrients: inorganic chemicals (particularly nitrogen, phosphorus and silicon) required for the growth of phytoplankton.

photosynthesis: the transformation of carbon dioxide and water to organic compounds (e.g., sugars) using sunlight as energy.

phytoplankton: minute aquatic plants and animals (e.g., algae), usually containing chlorophyll, that passively drift or weakly swim in a water body. Although zooplankton and other filter feeders eat phytoplankton, huge populations, called blooms, sometimes build up and can damage marine life and the environment.

planktonic: pertaining to plankton, minute aquatic plants and animals (e.g., algae) that passively drift or weakly swim in a water body.

predation: feeding upon other organisms.

protozoa: one-celled organisms.

pycnocline: the region of the water column characterized by the strongest vertical gradient in density, attributable to temperature, salinity, or both.

runoff: water that travels along impervious surfaces (e.g., streets, parking lots), usually after rain events, and empties into streams and nearshore environments. Runoff can contain substantial amounts of contaminants from urban and agricultural land uses (e.g., sewage pollution, fertilizer from lawns and agriculture, pesticides.)

nonpoint urban runoff: precipitation-related discharge of septic leachate, animal wastes, etc. from impervious surfaces, lawns, and other urban land uses.

sediment: particulate material lying on the sea floor (e.g., sand, gravel, silt, mud).

toxin (also biotoxin): a poisonous substance that is specifically produced by the metabolic activities of a living organism.

zooplankton: very small animals that drift or float passively with the current in water bodies.

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CREDITS

Acknowledgements

There are several individuals that made this report a reality. First, we would like to thank the people of the National Ocean Service, Special Projects Office, for their tireless efforts in creating this web series. Second, we would like to thank the Coastal Ocean Program within the National Ocean Service where one of the authors, Karen Bushaw-Newton, served her fellowship term. Finally, we would like to thank all the individuals who provided their expertise, photos, diagrams, and/or other types of input to this report. These include: D. Anderson, F. Van Dolah, T. Smayda, J. Sharp, P. Tester, D. Turgeon, D. Baden, V. Trainer, K. Steidinger, and S. Hällfors.
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Photo Credits

Many of the photos were gathered from NOAA archives or were generously provided from personal collections of NOAA staff members.

Others were contributed from outside of NOAA, and we gratefully thank the following institutions and individuals:

Photo 1. Peter Franks
Photo 2. Joann Burkholder
Photo 3. Baltic Sea Alg@Line Web site
Photo 4. Woods Hole Oceanographic Institute, The Harmful Algal Page Web site
Photo 6. Brian LaPointe
Photo 7. S. Hall
Photo 8. U.S. Geological Survey
Photo 9. Dr. Pat Tester, NOAA and Dr. Wayne Litaker, University of North Carolina, Chapel Hill
Photo 10. W. Bennett, U.S. Geological Survey
Photo 12. Carla Stehr

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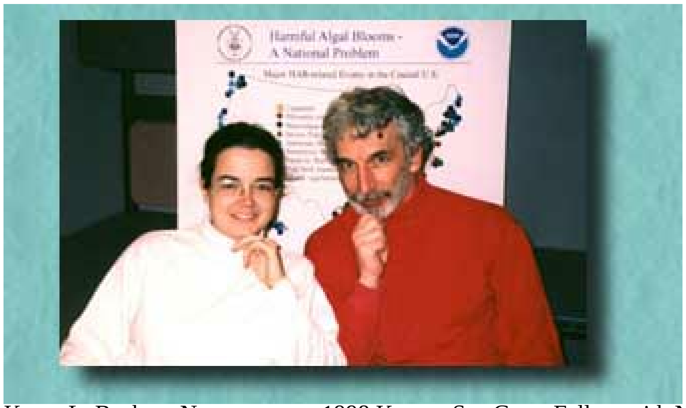
About the Authors



Karen L. Bushaw-Newton was a 1998 Knauss Sea Grant Fellow with NOAA's Center for Sponsored Coastal Ocean Research. She has a bachelor's of science in microbiology and a PhD in ecology from the University of Georgia. Dr. Bushaw-Newton has many research interests, including the biogeochemical cycling of organic matter in both freshwater and marine wetlands; the delineation, mitigation, and restoration of wetland habitats; and the use of wetlands as natural filtering systems for the control of excess nutrients and pollutants.

After 20 years as an active member of the plankton research community, Kevin Sellner recently joined NOAA's Center for Sponsored Coastal Ocean Research. He has focused his research over the last decade on the ecology of harmful algal blooms, and specifically on the fate of bloom production in coastal and oceanic systems. His primary interest has been to determine the importance of zooplankton grazing in blooms, but has also addressed the roles of sedimentation and microbial heterotrophy in bloom dissipation. Kevin has studied blooms from the Peruvian upwelling system, to the subestuaries of the Chesapeake Bay, to the enclosed Baltic Sea/Gulf of Finland. In his role at NOAA, he serves as the coordinator for the interagency research program known as ECOHAB (Ecology and Oceanography of Harmful Algal Blooms).

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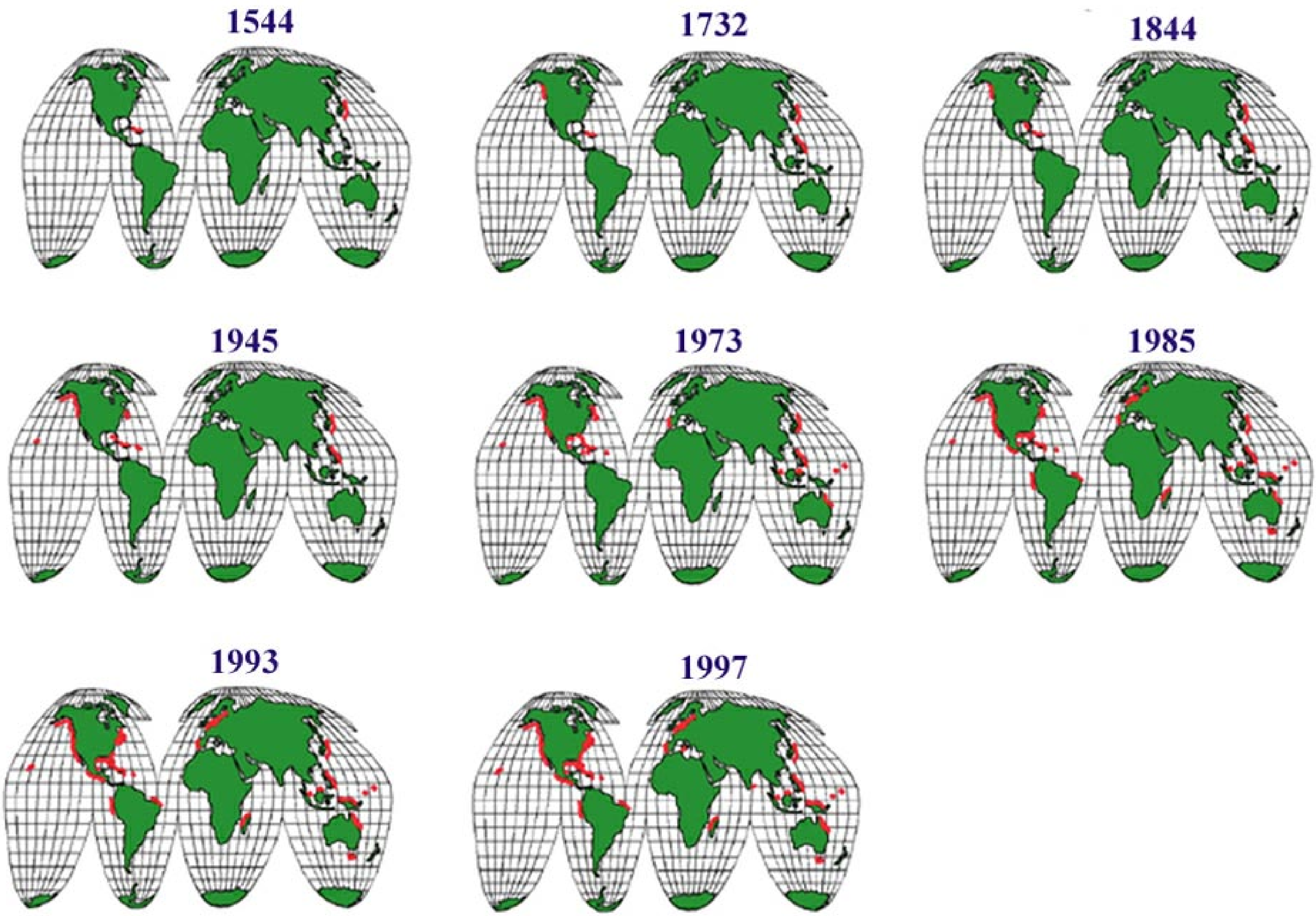

Figure 1. Worldwide HABs distribution, 1544-1997

Source: D.G. Baden, 1998

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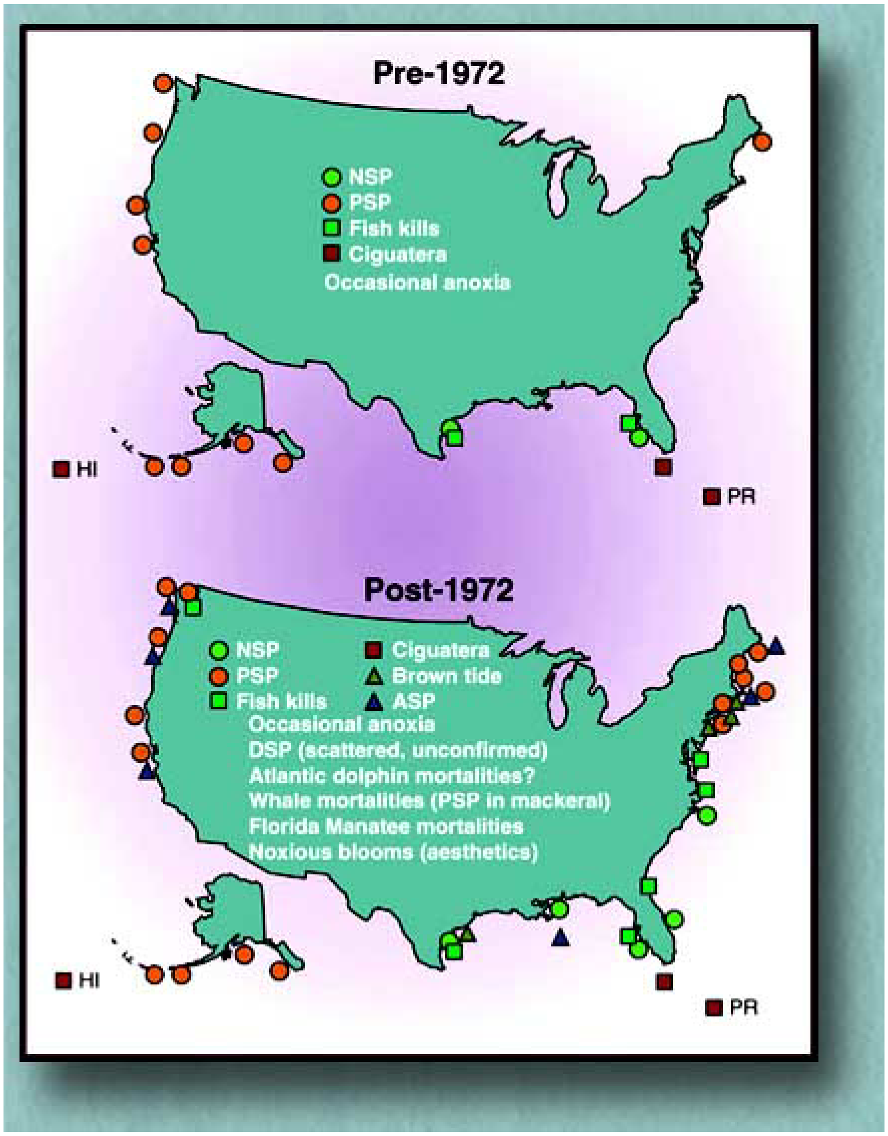

Figure 2. Location of HAB-related events in U.S. coastal waters before and after 1972

Source: National Office for Marine Biotoxins and Harmful Algal Blooms,
Woods Hole Oceanographic Institute; Turgeon et al. 1998.

Abbreviations: NSP, neurotoxic shellfish poisoning; PSP, paralytic shellfish poisoning;
ASP, amnesic shellfish poisoning; DSP, diarrheic shellfish poisoning

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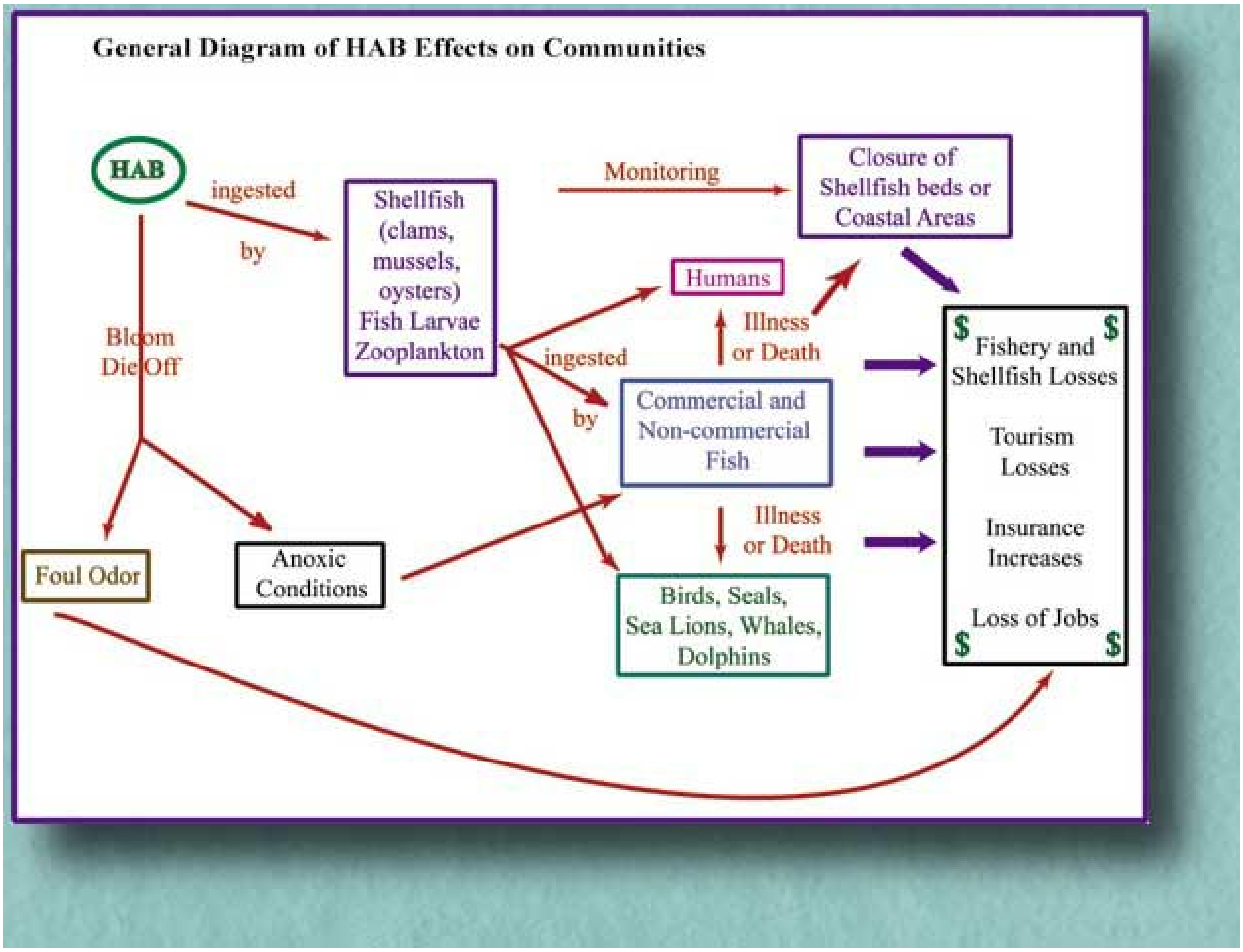

Figure 3. Effects of HABs

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Click on the image or the figure title to view the full size image.

Figure 4. Ciguatera fish poisoning (CFP) in the coastal United States, 1988-1998

Figure 5. Paralytic shellfish poisoning (PSP) in the coastal United States, 1988-1998

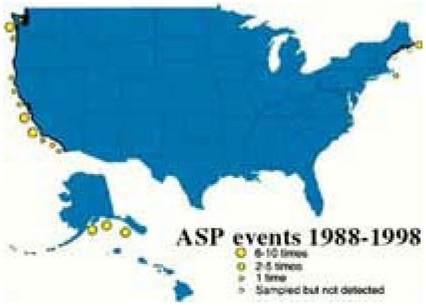

Figure 6. Amnesic shellfish poisoning (ASP) in the coastal United States, 1988-1998

Figure 7. Neurotoxic shellfish poisoning (NSP) in the coastal United States, 1988-1998

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Figure 4.

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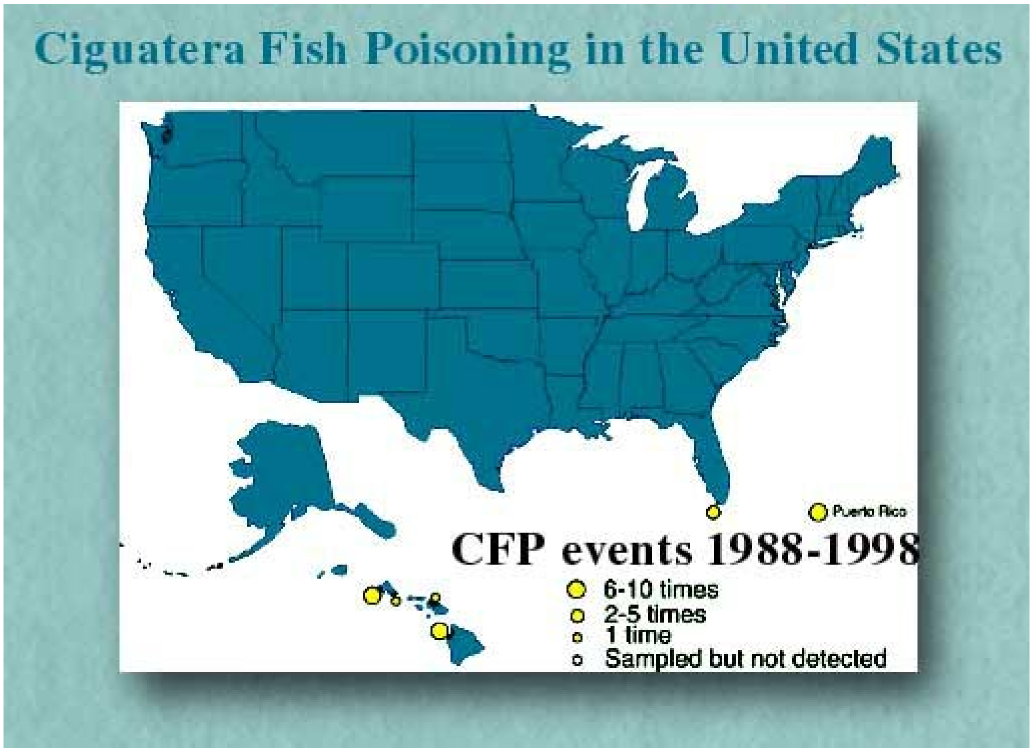

Figure 4. Ciguatera fish poisoning (CFP) in the coastal United States, 1988-1998

Source: National Office for Marine Biotoxins and Harmful Algal Blooms,
Woods Hole Oceanographic Institute; Turgeon et al. 1998.

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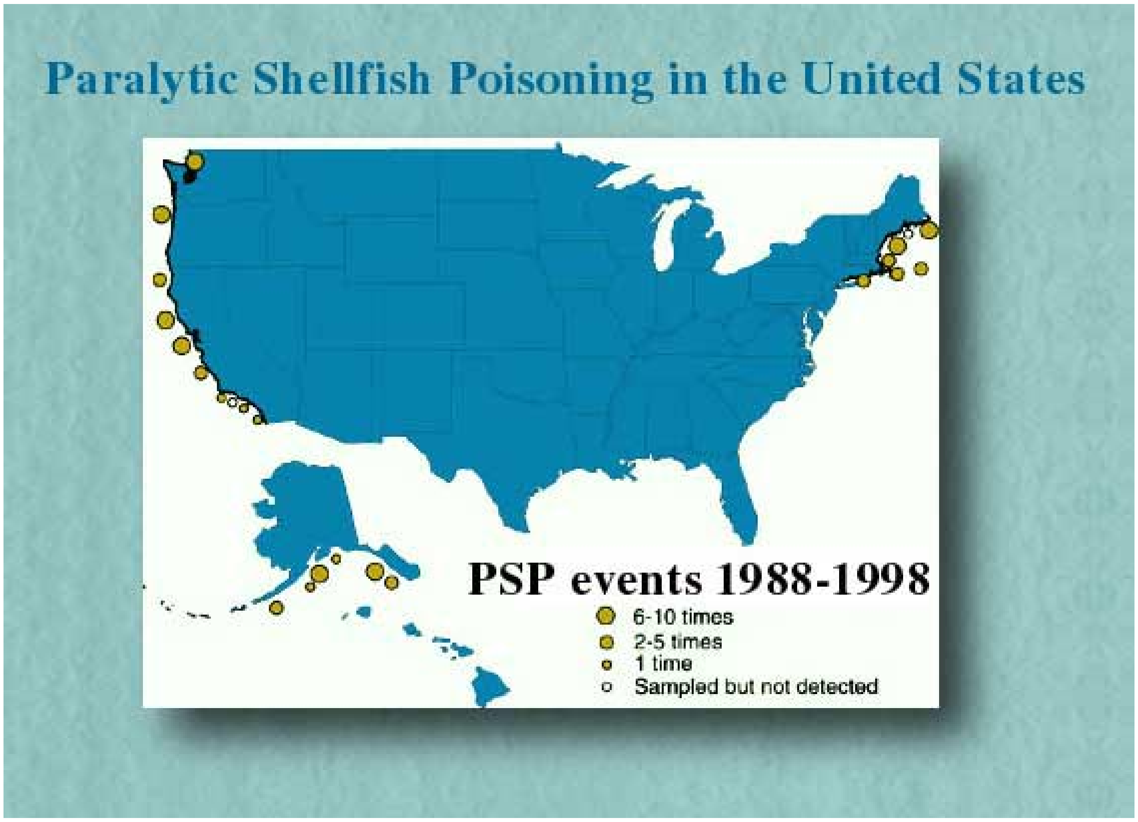

Figure 5. Paralytic shellfish poisoning (PSP) in the coastal United States, 1988-1998

Source: National Office for Marine Biotoxins and Harmful Algal Blooms,
Woods Hole Oceanographic Institute; Turgeon et al. 1998.

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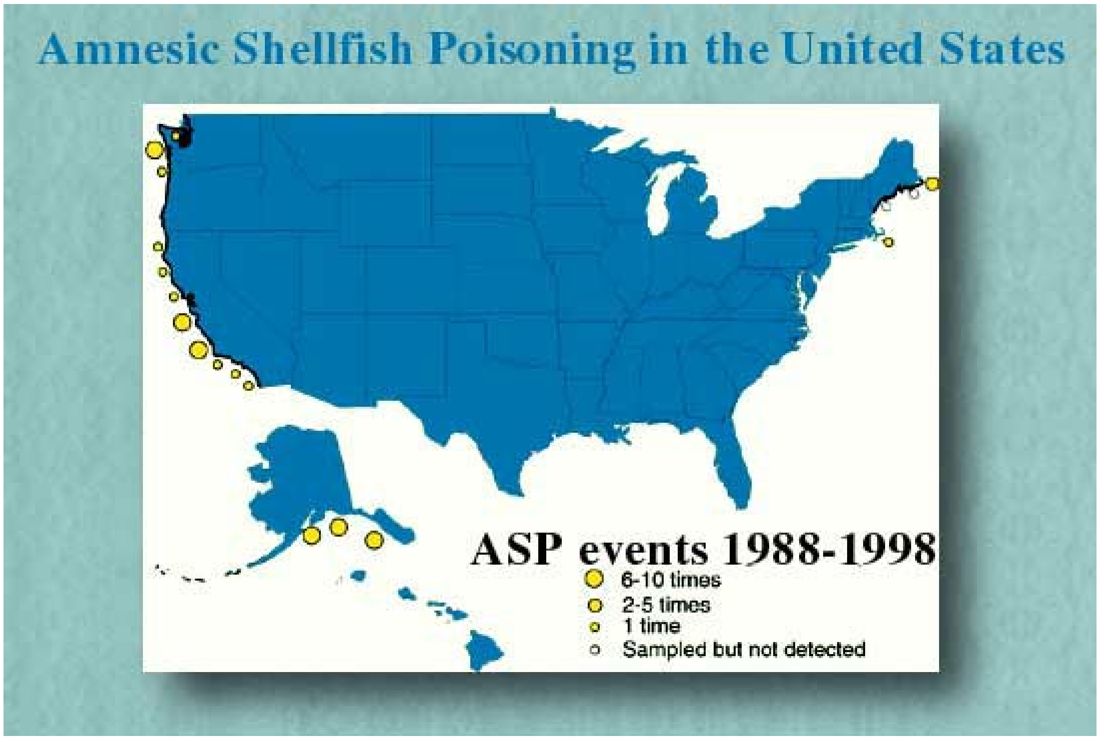

Figure 6. Amnesic shellfish poisoning (ASP) in the coastal United States, 1988-1998

Source: National Office for Marine Biotoxins and Harmful Algal Blooms,
Woods Hole Oceanographic Institute; Turgeon et al. 1998.

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Figure 7.

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Figure 7. Neurotoxic shellfish poisoning (NSP) in the coastal United States, 1988-1998

Source: National Office for Marine Biotoxins and Harmful Algal Blooms,
Woods Hole Oceanographic Institute; Turgeon et al. 1998.

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Table 1. HABs by species and coastal region

Coastal Geographic Area	***Documented HAB Problem***	***Responsible HAB Species***
Northeast (ME, NH, MA, CT, NY)	PSP	*Alexandrium* spp.
Mid-Atlantic (NY, NJ, RI, MA)	brown tide (reduced light penetration, severe scallop mortalities, recruitment failure, growth inhibition in scallops, adversely affects feeding of bivalves)	*Aureococcus anophagefferens*
DE, MD, VA, NC, SC, GA, FL	fish lesions	*Pfiesteria piscidaPfiesteria complex*
Southeast and Gulf of Mexico (TX, AL, FL, SC, NC)	NSP	*Gymnodinium breve*
Gulf of Mexico (TX)	brown tide (see above for associated effects)	*Aureocoumbra lagune*
Pacific Coast (CA, OR)	PSP	*Alexandrium cantenella*
	ASP	*Pseudo-nitzschia australis*
Pacific Coast (WA)	PSP	*Alexandrium cantenella Alexandrium acatenella Alexandrium tamarense*
	ASP	*Pseudo-nitzschia pungens P. australis P. pungens f. multiseries Pseudo-nitzschia pseudodelicatissima*
	finfish mortalities	*Heterosigma carterae (akashiwo) Chaetoceros concavicornis Chaetoceros convolutus*
Pacific Coast (AK)	PSP	*Alexandrium cantenella*
Tropical (HI, FL, Puerto Rico, US Virgin Islands)	ciguatera fish poisoning	*Gamberdiscus toxicus*
General to US Coasts East Coast/US (from FL to ME)	cyanobacterial blooms (varying degrees of toxicity in different organisms, negative aesthetic values, odor and taste problems, anoxia, toxins)	*Anabaena* sp. *Aphanizomenon* sp. *Microcystis* sp.
Southeast/US (FL as well as many other coastal areas of US)	macroalgae (seaweeds) (decreased seagrass productivity, coral reef decline, hypoxic/anoxic conditions)	***red*** *-Laurencia intricata, Spyridia filamentosa* ***brown*** - *Dictyota* sp., *Sargassum filipendula* ***green*** *-Enteromorpha* sp. *Colium isthmocladum Halimeda* sp.

(top)

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