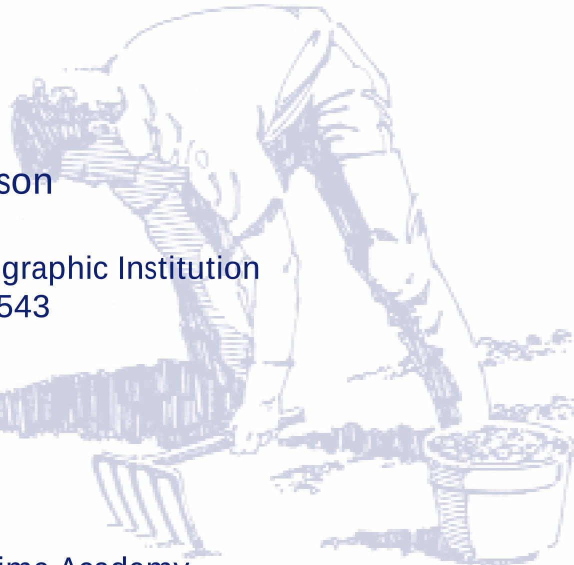
DANGER

Area Closed

Shellfish (oysters, clams, mussels, and other bivalve molluscs) in the area described below contain paralytic toxins and are not safe for use as food.

WHOI-2000-11

Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States



by

Donald M. Anderson
Porter Hoagland
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Yoshi Kaoru
Nanzan University
Nagoya, Japan

Alan W. White
Massachusetts Maritime Academy
Buzzards Bay, MA 02532

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Technical Report

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EXECUTIVE SUMMARY

Blooms of toxic or harmful microalgae, commonly called "red tides," represent a significant and expanding threat to human health and fisheries resources throughout the United States and the world. These phenomena take many forms, ranging from massive accumulations of cells that discolor the water to dilute, inconspicuous, but highly toxic populations. Ecological, aesthetic, and public health impacts include: mass mortalities of wild and farmed fish and shellfish; human intoxication and death from the consumption of contaminated shellfish or fish; alterations of marine food webs through adverse effects on larvae and other life history stages of commercial fish species; the noxious smell and appearance of algae accumulated in nearshore waters or deposited on beaches; and mass mortalities of marine mammals, seabirds, and other animals.

Many harmful algal blooms (HABs) have significant economic impacts. Shellfish closures, wild or farmed fish mortalities, and scared consumers who avoid seafood are well-recognized impacts of major HABs. While adverse health effects and lost sales of fish and shellfish products are direct costs, constrained development or investment decisions in coastal aquaculture due to the threat from outbreaks of toxic algae are examples of poorly understood or poorly quantified indirect or hidden costs. Lost marine recreational opportunities also are a significant cost of harmful algal bloom incidents.

HABs have increased steadily in both species complexity and geographical extent over the last several decades. In turn, the range of harmful effects and the magnitude of economic costs have also widened. This report provides the first comprehensive estimate of the economic impacts of HABs in the United States, focusing on both direct and indirect costs.

We estimate the economic impacts of HABs for events where such impacts were measurable with a fair degree of confidence during the six-year interval of 1987-92 (Table ES.1). Due to reporting limitations, the selected events are a subset of all outbreaks that occurred during the 1987-92 study period, and thus our aggregate economic impact underestimates the true impacts. “Economic impact” is defined broadly to mean either lost gross revenues in the relevant product or factor markets, expenditures for environmental monitoring and management, or other costs that would not have been incurred in the absence of HABs. In general, this measure is consistent with published estimates made for other natural catastrophes, such as hurricanes or earthquakes. Economic multipliers, often used to approximate the full ramifications of costs or losses as they are transferred through a local economy, are not used here. The calculation of economic multipliers in the absence of detailed data on market structure and interactions can be misleading, as multipliers can be sensitive to local market structure characteristics and to the quality of data that describe interactions among market sectors. Developing a description of local and regional markets for specific HAB events was beyond the scope of this project.

Table E.S.1: Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States

(Estimate is of 1987-1992 period, reported in 2000 dollars)

	Low	High	Average	% of Total
Public Health	$ 18,493,825	$ 24,912,544	$ 22,202,597	45%
Commercial Fishery	$ 13,400,691	$ 25,265,896	$ 18,407,948	37%
Recreation/Tourism	$ -	$ 29,304,357	$ 6,630,415	13%
Monitoring/Management	$ 2,029,955	$ 2,124,307	$ 2,088,885	4%
TOTAL	$ 33,924,471	$ 81,607,104	$ 49,329,845	100%
15 Year Capitalized Impacts (discounted at 7%)	$308,981,162	$743,270,485	$449,291,987	

Economic impacts are grouped into four basic categories: (1) public health impacts; (2) commercial fishery impacts; (3) recreation and tourism impacts; and (4) monitoring and management costs. Unless otherwise indicated, all estimates are reported in 2000 U.S. dollars.

Public Health Impacts

Human sickness and death from eating tainted seafood results in lost wages and work days. Costs of medical treatment and investigation also are an important part of the economic impact caused by such events. Cases of sickness and death from shellfish toxins are probably the most clearly documented among the different types of HAB impacts, since these cases are recorded by public health agencies in individual states as well as at the federal level.

For the 1987-92 period, the average public health impact due to shellfish poisoning from HABs was approximately $1 million per year (caused by paralytic, neurotoxic and amnesic shellfish poisoning, or PSP, NSP, and ASP respectively). This total is low because of highly effective state monitoring programs that detect toxic shellfish and keep contaminated products off the market. Another problem caused by toxic algae is the fish poisoning syndrome called ciguatera, caused by dinoflagellate toxins that move through the tropical food chain to the larger fish that then poison human consumers. Ciguatera affects predominantly the residents of, and visitors to, Florida, Hawaii, Puerto Rico, the U.S. Virgin Islands, Guam, and the Marshall Islands. Over the study interval, the economic impact of ciguatera poisoning varied from $18 million to more than $24 million per year, averaging $21 million. These estimates are low since ciguatera poisoning has occurred outside the tropical areas listed above due to exports of fish to other jurisdictions. Further, some seafood companies purchase insurance to cover potential ciguatera-caused liabilities, and there are court costs associated with ciguatera-related litigation – neither of which we were able to quantify for the study interval.

The total public health impacts from HABs ranged from a low of $18 million to a high of $25 million, averaging $22 million over the six-year interval. These figures represent approximately 45% of the total economic impacts from all causes.

Commercial Fishery Impacts

Commercial fishery impacts from HABs include wild harvest and aquaculture losses of fish and shellfish resources due to NSP, PSP, ASP, ciguatera, and brown tides. Annual impacts vary from $13 to $25 million with average annual impacts of $18 million. These figures clearly are underestimates because they do not include losses from PSP closures in several states where it was not possible to document the acreage closed or the value of the resource that was not harvested. The estimation of commercial fishery impacts is complicated further by the transfer of shellfishing effort from closed areas to areas that remained open and by fishermen switching to other fishing activities. In addition, the estimates do not include the value of wild fish kills or of lost opportunities for harvesting some untapped shellfish resources. Measuring the economic impacts of wild fish kills is problematic because many involve so-called “trash” fish that, by definition, have no market value. Also, the ultimate causes of fish kills often are unclear. For example, fish kills caused by the dinoflagellate *Pfiesteria* undoubtedly occurred in North Carolina during the six-year study interval, but state officials could not indicate which events were caused by *Pfiesteria* and which were due to other causes, such as low dissolved oxygen.

Another issue is that some currently untapped fishery "resources" have values that could be realized in the absence of HAB events, but such estimates are not included here. Examples include some shellfish resources of coastal Alaska, which are permanently quarantined due to persistent PSP toxicity and the logistics of sampling distant or remote resources. However, in order for such "lost opportunities" to be counted legitimately as economic impacts in this study, these fisheries must be demonstrated to be commercially viable. A plausible alternative reason for non-exploitation is that they are not profitable fisheries because there is insufficient demand or because harvesting is uneconomical. The annual economic impact estimates presented here include losses from these untapped resources only in certain special cases (e.g., surf clams in Alaska and on Georges Bank).

Recreation and Tourism Impacts

In 1991, a federal study estimated that expenditures by recreational fishermen for travel, food, lodging and equipment were 67 percent greater than expenditures for commercial fish landings. Although many experts argue that the impacts of HABs on recreation and tourism are important and potentially large, there are few available data describing the size of the impacts. Clearly, the economic impacts of HABs on recreational and tourism activities deserve substantially more attention than they have been given to date. In Florida, for example, recurrent red tides have been estimated to cause over $20 million in tourism-related losses every year. These impacts, as well as similar losses in Texas and other areas, are not well documented and thus are reduced to much lower levels in this study. The total annual estimates for recreation and tourism are, once again, underestimates. Efforts to measure recreation and tourism impacts must be undertaken at the local level because local environmental and socioeconomic conditions are critical determinants of changes in recreational benefits.

Estimates of economic impacts on recreation and tourism during the 1987-92 period range from zero to $29 million. The annual average is $7 million.

Monitoring and Management Costs

It is often the case that water monitoring tasks, including shellfish testing for PSP, NSP, and ASP, are spread across different divisions of state government, making it difficult to collect data on costs. Further, monitoring activities for both HABs and other water quality testing, such as shellfish sanitation, often are conducted by the same personnel. As a result, it is difficult to factor out those costs related specifically to HAB monitoring and management. Given this qualification, annual average monitoring and management costs for HABs are estimated at $2 million, distributed among twelve states: Alaska, California, Connecticut, Florida, Maine, Massachusetts, New Hampshire, North Carolina, New Jersey, New York, Oregon, and Washington. These costs include the routine operation of shellfish toxin monitoring programs, plankton monitoring, and other management activities.

Conclusions

Table ES-1 presents the annual aggregate economic impacts (in millions of 2000 dollars) of HABs in the United States during the 1987-92 period. The total costs average $49 million per year, ranging from $34 million to $82 million. Over the last several decades, the cumulative impacts thus approach $1 billion. Public health impacts are the largest component, representing more than 45 percent of total average impacts. Commercial fisheries impacts are the next largest component, representing 37 percent of the total. Recreation/tourism impacts account for 13 percent of the total, and monitoring/management impacts represent the remaining 4 percent. Further, it is important to note that expenditures made to improve monitoring and management likely resulted in decreases in impacts in the other categories.

These estimates are highly conservative and reflect the difficulties in compiling and assessing the impacts of phenomena for which economic studies are rare. The totals in Table ES-1 do not include the effects of economic multipliers, which would increase the estimates several-fold. They also do not include the value of untapped or unexploited resources, such as some of the extensive shellfish populations along Alaska's 30,000-mile coastline, presently closed to harvesting due to PSP toxicity. Likewise, the effects of delayed harvesting, as with temporary beach closures due to PSP, could not be estimated with any precision and thus are not included.

We note also that outbreaks of certain blooms may cause severe economic impacts that equal or exceed the annual averages for the selected study interval. For example, a 1976 New Jersey red tide caused losses estimated at more than $1 billion in 2000 dollars. Similarly, the 1997 *Pfiesteria* outbreak in the Chesapeake Bay is estimated to have cost the seafood industry $46 million. These single events exceed the annual average of HAB impacts for the entire nation.

The difficulties encountered in our efforts to generate a national estimate of HAB economic impacts underscore the need to modify the manner in which HABs are reported. At present, information on HAB events is fragmentary and inconsistent with respect to the level of detail provided. The duration, affected acreage or shoreline length, average toxicity levels, and values of affected coastal resources should be documented for each bloom in order to describe the overall economic significance of the incident. In addition, local and state governments should place much higher emphasis on quantification of economic impacts. Until local governments become capable of supplying site-specific impact information for each bloom incident, truly comprehensive and detailed national level aggregation of such impacts cannot be realized. Furthermore, the causes of economic impacts and the degree of their uncertainty should be included in any reports of economic impacts.

Overall, the economic impacts from HABs are diverse and large within the United States. Even with the highly conservative treatment given the impacts in this study, the annual costs are significant. Perhaps more importantly, many are recurrent, and show signs of increasing as the number of toxic and harmful algal species grows and as our reliance on the coastal zone for aquaculture, commerce and recreation expands. Prudent investment in research and monitoring can do much to reverse this trend and to reduce the annual impacts.

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1 INTRODUCTION

Ocean waters are home to thousands of species of microscopic algae which together comprise the base of the marine food web. Most of these species are harmless, and in fact are critical to the ocean's ecology and to the production of biomass at all levels of the marine food web. There are, however, a few dozen algal species which are associated with adverse impacts of many different types. The term "harmful algal bloom" or HAB is now used to describe the destructive and often visible "blooms" of these algae that kill fish, make shellfish poisonous, and cause numerous other problems in marine coastal waters. The one feature uniting these diverse phenomena is that they cause harm. In the past, the term "red tide" was used to describe many of these phenomena, but the term is potentially misleading and does not adequately describe the many different types of harmful outbreaks. Some algal species produce potent toxins which accumulate in shellfish that feed on those algae, resulting in poisoning syndromes in human consumers called paralytic, diarrhetic, amnesic, and neurotoxic shellfish poisoning (PSP, DSP, ASP, and NSP respectively). A related phenomenon called ciguatera fish poisoning (CFP) occurs when toxic algae living on coral reef seaweeds are consumed by herbivorous fish, which pass the toxins on to larger predators which then deliver the neurotoxins to human consumers. All of these toxins can also alter marine ecosystem structure and function as they are transferred through the food web, affecting fecundity and survival at multiple levels in ways that are still largely unquantified.

Some toxic blooms kill wild and farmed fish populations. Others are associated with irritating and toxic aerosols, due to the transport of toxins in sea spray. Even non-toxic algal species can cause problems through biomass effects - shading of submerged vegetation, disruption of food web dynamics and structure, and oxygen depletion as the blooms decay. Traditionally, the term HAB has referred to microscopic algae, but its interpretation has now been broadened to include blooms of macroscopic algae (seaweeds) which displace indigenous species, destroy habitat, cause oxygen depletion, and even alter biogeochemical cycles. The causes and effects of macroalgal blooms are similar in many ways to those associated with harmful microscopic phytoplankton species.

During the past several decades, HAB events have occurred in more locations than ever before throughout the United States and the world (Anderson 1989; Smayda 1990; Hallegraeff 1993). The number of algal species involved in such events has increased, there are more known toxins, more fisheries resources are affected, and the economic impacts of HAB outbreaks are larger as well. Whether or not this global increase in HABs is taking place because of enhanced nutrient and pollutant loadings from anthropogenic sources has been a topic of debate within the scientific community (e.g., Anderson 1989; Smayda 1990). Whatever the reasons, virtually all coastal regions of the United States are now subject to an unprecedented variety and frequency of HAB events. The United States is not alone in this respect, as nations throughout the world are increasingly faced with a bewildering and disturbing array of toxic or harmful species and impacts.

In the United States, the most significant economic and public health problems related to harmful algae during the 1987-92 interval that is the focus of this study were:

- Paralytic shellfish poisoning (PSP), which occurs in all coastal New England states as well as New York and along much of the west coast from Alaska to California. This problem has also extended to offshore areas in the Northeast, notably Georges Bank.
- Neurotoxic shellfish poisoning (NSP), and fish and marine mammal mortalities in the Gulf of Mexico and, more recently, extending northward to the coast of the Carolinas.
- Mortalities of farmed salmonids in the Pacific Northwest.
- Recurrent brown tides, causing mortalities of mussel populations, massive recruitment failure of scallops, and reduction of eelgrass beds around Long Island.
- Ciguatera fish poisoning (CFP), a malady associated with dinoflagellate toxins accumulated in tropical fish flesh, occurring in virtually all sub-tropical to tropical United States waters, including Florida, Hawaii, Guam, United States Virgin Islands, Puerto Rico, and many Pacific Territories.
- Amnesic shellfish poisoning (ASP), a sometimes fatal illness so named because one of its most severe symptoms is the permanent loss of short-term memory. The ASP toxin, domoic acid, has been detected in shellfish from both the West and East Coasts of the United States, and toxic *Pseudo-nitzschia multiseries* cells have been isolated from Gulf of Mexico water.
- Diarrhetic shellfish poisoning (DSP) which some consider the most serious and globally widespread phytoplankton-related seafood illness. The first confirmed incidence of DSP in North America occurred in 1990 and 1992 in Canada. DSP-producing species of phytoplankton such as *Dinophysis acuminata* and *Prorocentrum lima* occur throughout all temperate coastal waters of the United States, though no outbreaks of DSP have yet been confirmed.
- “*Pfiesteria*-like" dinoflagellates, affecting human health and fisheries in estuaries of the southeastern United States, and in particular the Neuse-Pamlico estuaries. Although *Pfiesteria* had been discovered by 1992, economic impacts of fish kills caused by this organism are not included in this study because no data could be obtained on the fish kills conclusively linked to *Pfiesteria* over the 1987-92 interval, or of the value of the dead fish. In the laboratory, human exposure to aerosols from toxic *Pfiesteria* cultures has been linked to short- and long-term neurotoxic symptoms. Fishermen and others working in or exposed to estuarine waters have complained of similar problems,

exemplified in the worst cases as a loss of neurocognitive ability. There are no estimates of the economic impacts of these human health effects in this report, again because of a lack of data.

- Blooms of macroalgae (seaweeds), in response to nutrient enrichment associated with coastal eutrophication. Opportunistic macroalgal species outcompete, overgrow, and replace seagrass and coral reef ecosystems. Once established, the macroalgal blooms may remain in an environment for decades until nutrient supplies decrease. Negative effects include reduced light availability to seagrasses and reef systems, leading to lower productivity, habitat loss from hypoxia/anoxia, and eventual die-off of sensitive species.

In this report, we provide a national estimate of the economic impacts of HABs from events for which such impacts were measurable with a fair degree of confidence during the interval 1987-92. (Unless otherwise indicated, all estimates are reported in 2000 U.S. dollars.) **Due to inadequate reporting, the events included here are only a subset of the HAB outbreaks that occurred during the six year study period. For this reason and others (discussed below) we believe that our aggregate economic impact estimates significantly underestimate the true impacts.** We acknowledge that “economic impact” is not an ideal measure of economic loss, but we employ the concept in this study because it is the predominant form in which damages are reported by coastal managers and by scientists in the published literature. We group economic impacts into four basic categories: 1) public health impacts; 2) commercial fishery impacts; 3) recreation and tourism impacts; and 4) monitoring and management costs. This is the first effort to estimate economic costs of HABs at the national level, so it is perhaps not surprising that in the course of this analysis, we encountered many unknowns and uncertainties with respect to quantifying impacts. These problems are discussed below.

2 METHODS

The following economic impact analysis is based mainly on a survey of experts from individual coastal states and the literature. Formal letters requesting economic impact information were mailed in August 1992 and February 1994 to individuals in certain heavily impacted states who were either knowledgeable about HAB impacts or who were likely to know others who could be contacted for more specific details. In total, more than 170 people were contacted by letter and by telephone to elicit economic impact information and to uncover details about individual HAB events. After a preliminary evaluation and synthesis of these data, topics requiring further data or analysis were identified. These were addressed through a new series of telephone calls and correspondence in 1997-99. We have summarized these data in the body of the report.

2.1 Definition of Economic Impacts

We define “economic impacts” broadly to mean either lost gross revenues in the relevant product or factor markets, expenditures for environmental monitoring and management, or other costs that would not have been incurred in the absence of HABs. In general, this measure is consistent with published estimates made for other kinds of natural catastrophes, such as hurricanes or earthquakes (e.g. Pielke and Landsea 1997; Pielke and Pielke 1997). As such, the estimates reported here represent a preliminary, but admittedly rough, approximation of the economic costs to the United States from the occurrence of HABs. Readers should keep the limitations of economic impact analysis in mind, realizing that it was developed as a purely descriptive technique. Its original purpose was to describe the economic structure of a region, to help understand economic interactions and linkages among sectors. In particular, it is not a form of benefit-cost analysis, and it should not be used to justify normative decisions (Propst and Gavrilis 1987).

Another consideration is that we do not apply “multipliers” in this report to capture the full ramifications of economic impacts. Multipliers can be sensitive to local market structure characteristics and to the quality of data that describe interactions among market sectors (Archer 1995; Propst and Gavrilis 1987). Developing a description of local and regional markets for specific HAB events was beyond the scope of this project. We have identified some studies of HAB impacts in which multipliers have been estimated and used, such as Maine's economic impact calculation for shellfishing closure of September 1980, and we recognize that it is possible to calculate multipliers for this kind of application (Loomis 1993). However, we believe that the calculation of economic multipliers in the absence of detailed data on market structure and interactions can be potentially misleading, creating a perception of exaggerated economic costs of HAB events (e.g. Hunter 1989). Furthermore, the occasional misuse of economic impact analysis to make normative decisions to justify investments, for example, is made all the worse when impacts are multiplied.

2.2 Economic Impacts are not an Ideal Measure of Social Costs

Economic impacts as defined here are not an ideal measure of the costs of HABs to society. Under ideal circumstances, we would like to obtain a measure of lost consumer and producer surpluses in the relevant markets due, say, to shifts in demand or supply curves. We demonstrate this point in Figure 2.1, which depicts supply and demand in a commercial fishery during one season[1]. Assume that we are considering the costs associated with the closure of a fishery due to a HAB event. In a typical case, this can be represented by a shift of the supply curve, which itself is the horizontal sum of marginal cost schedules for individual firms, from S_0 to S_1. The effect is a reduction in the supply of fish to the market, from F_0 to F_1, and an increase in the price of fish, from P_0 to P_1. Prior to the closure, the net benefits flowing from the fishery are the sum of producers' surplus (E+F+G) and consumers' surplus (A+B+C+D). After the closure, producers' surplus now becomes area B+E and consumers' surplus is reduced to area A. The net economic loss associated with the closure is therefore C+D+F+G. Compare this theoretically correct, but often more difficult to obtain, measure with lost gross revenues from the closure (G+I). It should be clear that the latter is not a very close approximation of "true" economic losses. In particular, although G is a true economic loss, I represents resources that can be productively invested or utilized elsewhere in the economy.

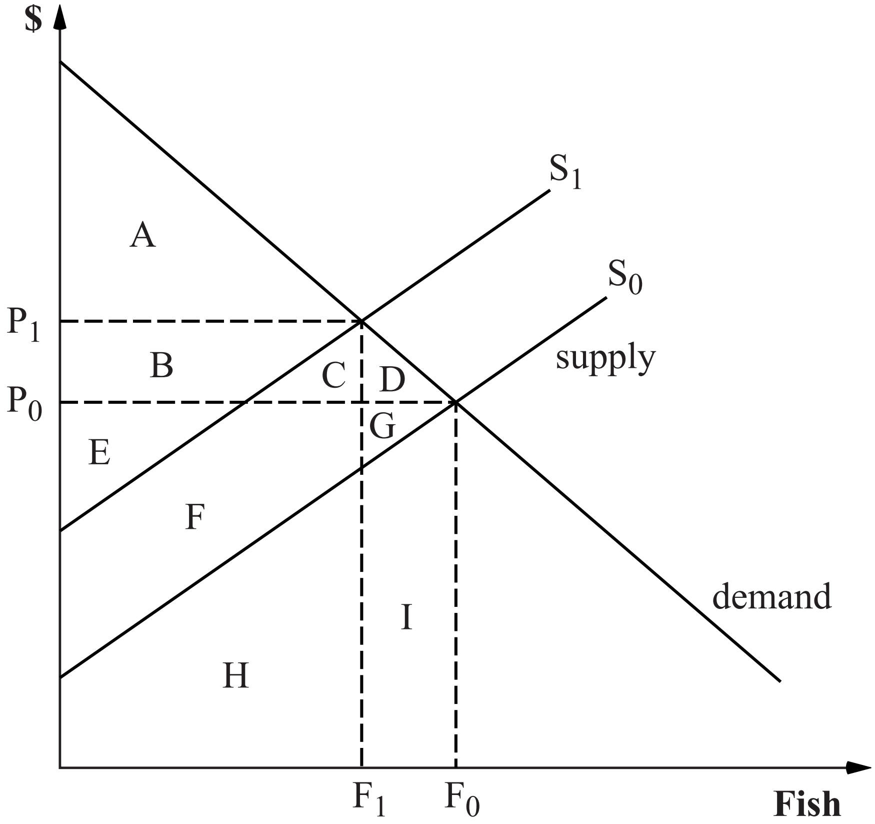

Figure 2.1. Economic costs of a HAB event in a commercial fishery.

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[1] We examine the case of the lower section of the traditional backward bending supply curve. This example is relevant to the case of a fishery managed to maximize economic yield.

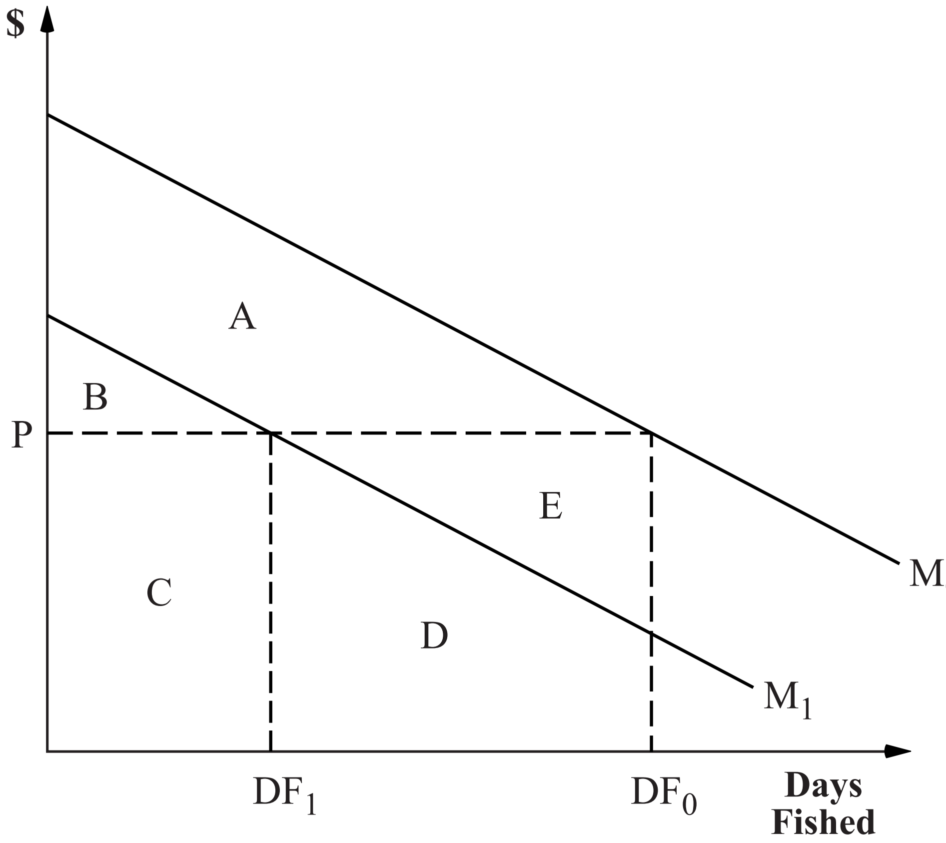

Figure 2.2 Economic costs of a HAB event in a recreational fishery.

The case of a recreational fishery is represented in Figure 2.2. In the present study, we have estimated economic impacts as the product of lost days fished, e.g., due to a fishery closure, times average daily recreational expenditures. (Note that some recreational fisheries may have a commercial component, complicating the analysis.) However, this measure does not represent a true economic cost of a HAB event because, when expenditures are not made, individual recreational fishermen incur no costs. Nevertheless, there may be consumer surplus losses, which represent true economic costs. Assume that there exists a recreational "market" demand curve (M) along which fishing success (i.e., catch rate) is assumed to be constant (Anderson 1986). Prior to a HAB event, gross benefits are equal to area A+B+C+D+E and expenditures are equal to area C+D+E. Net benefits are therefore equal to area A+B. Now assume that an algal bloom results in the closure of some fishing areas, causing reduced catch rates in areas that remain open, say, due to increased fishing pressure in the latter.[2] Because fishing success declines, area closures will result in the contraction of recreational market demand for each level of aggregate days fished: for example, M_0 shifts down to M_1. At the current level of fishing expenditures of

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[2] Other scenarios are certainly possible. For example, a bloom event may result in the closure of an entire recreational fishery. Closures could be temporal, instead of spatial, limiting the total days fished. Analyses of other scenarios should be straightforward.

P, a new equilibrium of DF_1 aggregate days fished is established. Following the logic described above, net benefits at the new level of days fished are equal to area B. The loss in consumer surplus from the closure is equal to area A. Note that there is no explicit market for days fished. The demand for days fished is a "non-market" demand. Estimation of this demand, and therefore losses to a recreational fishery from a HAB event, requires the application of specialized economic methods.

2.3 Ex Ante vs. Ex Post Impacts

The point in time at which impacts are measured also must be considered. When a commercial or recreational fishery is closed *ex ante*, then the appropriate measure of economic effects is the sum of lost consumer and producer surpluses, as described in the previous paragraphs. However, if commercial fish have been harvested already and the product subsequently prevented from reaching the market because toxicity exceeds safe levels, then it is appropriate to add harvest costs (area I in Figure 2.1) to the measure of economic losses. Harvest costs are included because they are a measure of resources that have been utilized to no productive effect. Another example is the occurrence of a HAB that affects an operating coastal aquaculture facility that must subsequently incur additional depuration costs or dispose of tainted product. In both examples, there may be additional costs, such as higher tipping fees, associated with the disposal of the tainted seafood.

2.4 Nonmalleable Factors

Another source of economic costs relates to the ease with which capital or labor can be transferred to other productive activities. In the economic models described above, we assume that fishing vessels, processing plants, fishermen, etc. will immediately and costlessly switch to their next best alternative activity. In other words, capital and labor are assumed perfectly "malleable." However, when examining specific cases, we may find that this assumption is not valid. Good examples include empty hotel rooms or slowed restaurant trade resulting from reduced coastal tourism during a HAB event. As another example, it may be costly for fishermen to re-rig their boats or steam to another fishing ground when a HAB closure has been declared. Often, economic impact studies will assume that capital and labor is completely *non*malleable. In this report, where feasible, we point out any malleability assumptions in the studies that we cite.

2.5 Other Types of Impacts

We have collected data on other types of impacts. The economic impacts that we measure in the form of hospitalization costs or monitoring and management costs are true economic costs. These activities represent the allocation of scarce medical and management resources that otherwise would be devoted to other health problems or public goals. Interestingly, these activities help to mitigate the larger "potential" costs of HAB events. For example, monitoring might prevent the consumption of toxic seafood, and hospitalization might reduce mortality from seafood consumption. As a result, there may be net benefits from undertaking these activities. (The existence of net benefits will depend upon a comparison of the total costs and total benefits of these activities.) Our economic impact analysis does not account for the benefits of these types of mitigating activities.

2.6 Distribution of Impacts

Note that some firms in the relevant market actually may benefit from a HAB event. For example, if a fishing location is closed because of a HAB event, a firm fishing for the same species in a location that remains open may actually see an increase in price for its product. Although there is a clear net loss at the market level, local net gains or net losses may occur, and the distribution of gains and losses may not be uniform across all localities. Unless demand is perfectly elastic with respect to price, consumers will unambiguously lose because of price increases when supply is reduced as a consequence of a HAB event. Some will even be unwilling to purchase the fish or shellfish at the new higher price.

2.7 Usefulness of the Economic Impact Measure

Even though our measure of economic impacts is not theoretically correct, it can still be useful. First, this measure is very easy to collate and calculate. To our knowledge, there are few studies that have examined the true economic costs of HAB events, but many have estimated economic impacts. Second, this approach can give an idea of the scale of the problem. If economic impacts are found to be large in any particular instance, it indicates that we need to take a closer look at the true economic losses. Third, the geographic location of economic impacts can give an estimate of where local losses occur, and the type of impact can help us identify the relevant market. When combined with an understanding of the relevant product or factor market, we may be able to predict where local net gains might occur. Thus, economic impact analysis can give a feel for the distributional effects of a HAB event.

2.8 Study Interval

We examine a “window” of impacts resulting from events during the six-year period from 1987 to 1992 to develop an estimate of “annual” economic impacts. There is still a great deal of uncertainty about the frequency and spatial distribution of HAB occurrences. Because of this uncertainty, the choice of a shorter period could result in either under- or over-estimates of economic impacts, depending upon when and where HAB events occurred. The six-year period was the longest period for which we could collect a consistent set of data within the constraints of the project. Although our choices about the timing and duration of the study period are somewhat arbitrary, we believe that it gives us a reasonable interval within which to develop credible estimates of the annual economic impacts of HAB events at the national level.

2.9 Data

Although we made an effort to gather economic impact data as comprehensively as possible, both the type and amount of available data were limited. **Most coastal states have neither conducted economic analyses of HABs nor collected data that can be used to generate reliable quantitative economic impact estimates.** In many cases, the complex physical and ecological characteristics of the coastal environment make it difficult to determine whether an algal bloom is the immediate and relevant cause of certain coastal phenomena such as fish kills, oxygen depletion, or seagrass dieoffs. Moreover, local experts often differ substantially in their opinions about the magnitude of economic impacts from HABs.

In Appendix A, we summarize HAB events reported informally by individual coastal state experts to a "national office" of the *ICES Center for the Exchange of Information on Exceptional Plankton Blooms*, located at the Woods Hole Oceanographic Institution. Although the data are rudimentary in nature, these are the only national compilations of bloom data. In Appendix B, we present the names and affiliations of the individuals with whom we corresponded.

3 PUBLIC HEALTH IMPACTS

Human sickness and death from eating tainted seafood results in lost wages and work days. Costs of medical treatment and investigation also are an important part of the economic impact caused by such events. Individuals who are sick may also experience pain and suffering. In theory, these feelings could be quantified in economic terms, but we make no attempt to do so here. Cases of sickness and death from shellfish toxins are probably the most clearly documented among the different types of HAB impacts. Because of the high level of public interest in seafood safety, these cases are recorded by public health agencies in individual states as well as at the federal level.

3.1 PSP, NSP, and ASP Illnesses

During 1978-87, paralytic shellfish poisoning (PSP) was a minor cause of seafood-borne illness in the United States, according to data on illness cases reported to the Center for Disease Control (CDC) in Atlanta (Table 3.1). Only two deaths due to PSP were reported during this period. Nishitani and Chew (1988) present data on reported PSP cases during 1979-87 in the four Pacific Coast states: Alaska, Washington, Oregon, and California. These data show that in the more recent years there were far fewer PSP cases than in the earlier years, especially in California. A separate report from the U.S. Food and Drug Administration identifies shellfish poisoning cases for the 1973-92 period (Rippey 1994). The reported number of PSP sickness cases varies widely across these sources. For example, the CDC reports no PSP cases in 1987, but Nishitani and Chew (1988) report seven PSP cases in Alaska in that year. Because reports to CDC are voluntary, we believe that the CDC database underestimates the number of PSP sickness cases in any year.

For the 1987-92 period, we show in Table 3.2 our estimate of the public health impacts resulting from PSP, NSP, and ASP. Impacts ranged from $11,098 to $4.84 million, with an average cost of $1.02 million. The illness and death cases presented in Table 3.2 were compiled from the information in Appendix A and the tables in Nishitani and Chew (1988) and Rippey (1994).

A few cases of respiratory complaints and eye irritation are reported in Appendix A. Aerosolized toxins, such as those from *Gymnodinium breve* in Florida, may well have caused some of these cases. However, these complaints are not included in Table 3.2 because of the difficulty in quantifying the number of cases as well as their impacts.

3.1.1 Illness Costs

We adopt the estimates used by Todd (1995) for PSP illnesses (C$1500 [1993 Canadian dollars] per reported illness and C$1180 [1993 Canadian dollars] per unreported illness) to estimate the costs of foodborne disease due to PSP, NSP, and ASP in the United States. Unreported illnesses

Table 3.1: Illness Due to Natural Seafood Toxins in the United States Reported to the Center for Disease Control

	Ciguatera		**PSP**	
Year	**Outbreaks**	**Cases**	**Outbreaks**	**Cases**
1978	19	56	4	10
1979	21	97	1	3
1980	15	52	5	116
1981	30	219	1	-
1982	8	37	-	5
1983	13	43	-	-
1984	18	78	-	-
1985	26	104	2	3
1986	18	70	-	-
1987	11	35	-	-
Total	**179**	**791**	**13**	**137**

NOTE: An outbreak is an incident involving two or more sick individuals, and a case is a single ill person. Source: F. E. Ahmed (ed.), 1991. Seafood Safety, p. 89.

Table 3.2: Shellfish Poisoning Impacts from Harmful Algal Blooms

Year	State	Type	Reported	Unreported[a]	Impacts[b] (000s)
1987	Florida North Carolina Alaska	PSP NSP PSP	3 47 7	27 423 63	$633
1988	Washington Alaska	PSP PSP	5 3	45 27	$89
1989	New York California	PSP PSP	2 2	18 18	$44
1990	Massachusetts Alaska[c]	PSP PSP	8 2	72 18	$4,836
1991	California Washington/Oregon Alaska	PSP ASP PSP	11 28 5	99 252 45	$488
1992	Alaska	PSP	1	9	$11
Avg.			**21**	**185**	**$1,016**

[a] Reported illnesses are estimated to be 10 percent of all illnesses due to HAB events (Todd, pers. comm., 1997).

[b] Economic impacts are estimated at $1,374 per reported illness, $1,081 per unreported illness,and $4.73 million per death (2000 dollars). (Please see the text for references.) Values in the table are reported in 2000 dollars.

[c] Includes one mortality in Alaska.

Sources: Appendix A, Nishitani and Chew (1988), and Rippey (1994).

do not, by definition, incur medical and transportation costs. Illness costs include lost productivity due to sick days, costs of medical treatment and transportation, and costs associated with investigations for the cause of the sickness.[3] The figures we use are downward revisions of earlier estimates published by Todd (1989a, 1989b). Because cost information is not available specifically for NSP or ASP illnesses, we apply the cost estimates for PSP cases to these illnesses.

During the study period, one person died from PSP in Alaska in 1989. Our estimate of the economic impact per death is based upon labor market studies of the implicit value of life (Viscusi 1993). Such studies have been used to develop estimates of both the value of life and the costs of nonfatal illnesses from empirical data that relate wage premiums to job risks. These studies suggest that there is a range of the value of life from \$3 to \$7 million, and we use an estimate of \$4 million for the one life lost in Alaska (1993 dollars).

3.1.2 Unreported Illnesses

We know that a substantial number of illnesses caused by HABs remain unreported. However, no reliable method has been proposed for extrapolating from the reported cases to estimate the true number of illnesses. Todd (1989a) proposed multiplying the number of reported cases by a factor of ten to estimate the total. Until better information on unreported illnesses is available, we believe that the most conservative way to report our findings is to provide cost estimates based upon actual, reported poisoning episodes, using Todd's multiplier, without additional arbitrary adjustments.

Our estimate of public health costs of unreported illnesses is much lower than the annual PSP costs of \$2.31 million (2000 U.S. dollars) estimated for the United States by Todd (1989a), who employed much larger estimates of costs per illness (C\$6000 in 1985 Canadian dollars) during a different period (1978-82). Todd's calculation also accounts for the likelihood that unreported cases are very likely to be less serious than reported cases, implying that there may be lower associated medical treatment and investigation costs. Following Todd's lead, we multiplied the number of reported cases during 1987-92 by 10, and weighted reported illnesses by the higher cost per illness. Our annual average estimate of the public health impacts due to shellfish poisoning was \$1.02 million (2000 U.S. dollars), a value that is substantially less than Todd's (1989a) estimate.

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[3] Labor market studies have also been used to estimate the implicit value of nonfatal injuries. These estimates fall in the range of \$25 to \$50 thousand (Viscusi 1993). Other methods for valuing morbidity effects, such as survey techniques, result in estimates that range from \$700 to \$3500, which are more consistent with Todd's estimates of illness costs (e.g., Viscusi et al. 1987). Note, however, that survey methods are very sensitive to perceptions of risks.

3.2 Ciguatera

Another problem caused by toxic algae is the syndrome called ciguatera fish poisoning (CFP), which is linked to dinoflagellate toxins that move through the tropical food chain to the higher predators. Although ciguatera technically is not a "bloom" phenomenon, we investigate it because it originates with toxic microalgae and has significant economic and public health costs (e.g. Ragelis 1984). In Table 3.3, we report the number of human sicknesses due to ciguatera poisoning in Florida (Weisman, pers. comm., 1997), Hawaii (Hokama, pers. comm., 1994), Puerto Rico (Tosteson, pers. comm., 1997), the U.S. Virgin Islands (Tosteson, pers. comm., 1997), Guam (Haddock, pers. comm., 1997), and the Marshall Islands (Ruff 1989). We develop our own estimates of sicknesses in Palau, Micronesia, the Northern Mariana Islands, and American Samoa based on the incidence of ciguatera illnesses in the Marshall Islands.[4] To be consistent across all regions, we adopt Todd's (1995) estimate of the illness costs (1993 Canadian dollars) due to ciguatera of C$1100 (US$1,007 [2000 dollars]) per reported case and C$750 (US$687 [2000 dollars]) per unreported case. This may result in an overestimate of ciguatera costs in Puerto Rico, as Tosteson (pers. comm., 1997) thinks that the costs per reported case are lower in Puerto Rico—about US$532 per reported case (2000 dollars).

Experts differ on the ratio of reported to unreported illnesses in each jurisdiction. We use the following ratios: 1:4 for Florida (Weisman, pers.comm., 1997); 1:10 for the Marshall Islands, Palau, Micronesia, the Northern Mariana Islands, and American Samoa (our own estimate); and 1:100 for Hawaii, Guam, Puerto Rico, and the U.S. Virgin Islands (Tosteson, pers. comm., 1997 and our own estimates). The economic impact varies from $17.72 million to $24.28 million per year, averaging $21.19 million on an annual basis. It is clear that the economic impacts due to ciguatera poisoning account for most of the public health impacts from toxic algae. Nevertheless, we may not be estimating the true scale of the problem. Ragelis (1984), for example, notes that ciguatera poisoning often occurs outside of tropical areas due to exports of tropical fish to other jurisdictions. Further, some seafood companies now purchase insurance to cover potential ciguatera-caused liabilities, and there are also court costs associated with ciguatera-related litigation, which has become quite common. We have no estimates of these costs, so again, our estimates are conservative.

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[4] We include the Marshall Islands, Palau, and Micronesia in our U.S. estimate because all three nations have a "compact of free association" with the United States and all three are heavily dependent upon the United States for foreign aid. The Northern Mariana Islands is a Commonwealth in political union with the United States, much like Puerto Rico. American Samoa is a territory of the United States much like the U.S. Virgin Islands.

Table 3.3: Public Health Impacts of Ciguatera

(estimates of reported and unreported illnesses for each jurisdiction)

Year	***Florida***[a]		***Hawaii***[b]		***Puerto Rico***[b,c]		***Virgin Islands***[b,c]		***Guam***[b]		***Marshall Islands***[d]		***American Samoa***[e]		***Northern Mariana Islands***[e]		***Palau***[e]		***Micronesia***[e]		***Totals***		***Estimated impacts (2000 $U.S. millions)***[f]
1987	250	750	90	8910	200	19775	6	593	5	495	264	2376	30	270	32	290	7	66	51	456	935	33982	**26.52**
1988	250	750	77	7623	200	19775	6	593	15	1485	264	2376	30	270	32	290	7	66	51	456	932	33685	**26.29**
1989	250	750	71	7029	200	19775	6	593	4	396	264	2376	30	270	32	290	7	66	51	456	915	32002	**25.01**
1990	250	750	28	2772	162	16025	5	481	11	1089	264	2376	30	270	32	290	7	66	51	456	840	24575	**19.36**
1991	250	750	61	6039	162	16025	5	481	6	594	264	2376	30	270	32	290	7	66	51	456	868	27347	**21.47**
1992	250	750	48	4752	162	16025	5	481	2	198	264	2376	30	270	32	290	7	66	51	456	851	25664	**20.18**

a) Weisman (pers.comm. 1997) estimates that only one in four ciguatera cases in Florida are reported.
b) We assume only one in 100 ciguatera cases are reported in these jurisdictions, based upon Tosteson's (pers. comm. 1997) estimate for Puerto Rico.
c) Tosteson (pers.comm. 1997) estimates reported ciguatera cases are 0.6 percent of the population during 1987-89 and 0.5 percent of the population during 1990-92.
d) Ruff (1989) estimates that only one in ten ciguatera cases are reported in the Marshall Islands.
e) We estimate that one in ten ciguatera cases are reported in these jurisdictions, based upon Ruff's (1989) estimate for the Marshall Islands. We use also the average incidence of ciguatera in the Marshall Islands as a hazard rate for these jurisdictions.
f) Todd (pers.comm. 1997) estimates ciguatera illness costs of Can$1100 (1993 dollars) per reported case and Can$750 (1993 dollars) per unreported case.

4 COMMERCIAL FISHERY IMPACTS

In Table 4.1, we present HAB events for which commercial fishery impact information was obtained. Most of these events are described in further detail in Appendix A. Annual impacts vary from $13.82 to $25.88 million. Average annual impacts are $18.95 million (2000 dollars).

4.1 Wild Harvest and Aquaculture Losses

We estimate total commercial harvest losses during a November 1987 to February 1988 *G. breve* bloom in North Carolina (Tester et al., 1991) to be $8.27 million. We estimate total impacts of $17.64 million arising from the deaths of farmed Atlantic salmon killed by phytoplankton blooms in Washington in 1987, 1989, and 1990 by multiplying the market price of salmon by the weight of lost fish. Two commercial shellfishing interests, Taylor United and the Coast Oyster Company, estimate a combined $1.22 million loss incurred during a shellfish recall resulting from the detection of PSP toxins in Washington State shellfish. Several other HAB events are further clarified in the following sections.

4.1.1 Brown Tide Impacts on Bay Scallop Harvests in New York

In 1985, a brown tide bloom first appeared in the Peconic Estuary, Long Island and has reappeared since on a regular basis. The most significant economic impact was the eradication of the Peconic's nationally significant bay scallop stocks. The Suffolk County Department of Health Services estimates that the 1982 value of commercial landings of bay scallops from the Peconic Estuary was $12.55 million (SCDHS 1992). (A multiplier may have been used to arrive at this estimate.) However, Tettelbach and Wenczel (1993), citing a report by Rose (1987), estimate the value of commercial bay scallop landings from New York waters for the years preceding the 1985 brown tide incident at a much lower level, averaging $2.60 million (2000 dollars) (Table 4.2).[5] In the only study we are aware of that looks at lost surpluses (instead of lost sales) from a HAB event, Kahn and Rockel (1988) estimate annual total consumers' and producers' surplus losses from the elimination of bay scallop populations in Long Island waters at a very similar level of $3.27 million (2000 dollars).

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[5] Landing values are measured at the average U.S. bay scallop price of $4.91/lb. (1984 dollars). The average price was $4.46/lb. in 1985. Estimates of lost output have been converted into 2000 dollars in the table.

Table 4.1: Commercial Fishery Impacts*

(2000 $U.S. millions)

Year	Incident	Type	State	Estimated Impacts	Total Annual Estimated Impacts
1987	Harvest losses of clams, oysters, scallops, and finfish	NSP	North Carolina	8.27	
	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Bay scallop mortality	BT	New York	3.27	
	Farmed fish kills	HAB	Washington (Cypress Island)	0.75	
	Bitter crab disease in tanner crabs	PD	Alaska	0.16	
	Closure of surf clam fishery	PSP	Alaska	5.72	21.33
1988	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Bay scallop mortality	BT	New York	3.27	
	Bitter crab disease in tanner crabs	PD	Alaska	0.16	
	Closure of surf clam fishery	PSP	Alaska	8.29	14.89
1989	Farmed fish kills	HAB	Washington (Cypress Island)	11.01	
	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Bay scallop mortality	BT	New York	3.27	
	Closure of surf clam fishery	PSP	Massachusetts (Georges Bank)	0.13	
	Lost value of unprocessed geoducks and bitter crab disease in tanner crabs	PSP, PD	Alaska	1.49	
	Closure of surf clam fishery	PSP	Alaska	6.15	25.27
1990	Farmed fish kills	HAB	Washington (Central Puget Sound)	5.88	
	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Closure of surf clam fishery	PSP	Massachusetts (Georges Bank)	-0.01	

Table 4.1: Commercial Fishery Impacts (Continued)

Year	Incident	Type	State	Estimated Impacts	Total Annual Estimated Impacts
1990	Bay scallop mortality	BT	New York	3.27	
	Lost value of unprocessed geoducks and bitter crab disease in tanner crabs	PSP, PD	Alaska	1.49	
	Closure of surf clam fishery	PSP	Alaska	-0.39	13.40
1991	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Bay scallop mortality	BT	New York	3.27	
	Closure of surf clam fishery	PSP	Massachusetts (Georges Bank)	0.23	
	Harvest losses of razor clams	ASP	Oregon	0.11	
	Lost value of unprocessed geoducks and bitter crab disease in tanner crabs	PSP, PD	Alaska	1.49	
	Closure of surf clam fishery	PSP	Alaska	8.04	16.31
1992	Lost sales of recreational fish	CFP	Hawaii	3.17	
	Bay scallop mortality	BT	New York	3.27	
	Product recall costs for one firm	PSP	Washington	1.22	
	Closure of surf clam fishery	PSP	Massachusetts (Georges Bank)	0.26	
	Harvest losses of razor clams	ASP	Oregon	0.21	
	Lost value of unprocessed geoducks; bitter crab disease in tanner crabs; and PSP event in Dungeness crab fishery	PSP, PD	Alaska	1.99	
	Closure of surf clam fishery	PSP	Alaska	9.14	19.25

*Not included are unknown impacts from unexploited resources of surf clams and tellin in the Bering Sea and roe-on-scallop from Georges Bank (see the text for more detail). Key to type of harmful algae bloom: ASP=amnesiac shellfish poisoning; BT=brown tide; CFP=ciguatera fish poisoning; HAB=harmful algae bloom (not otherwise identified); NSP=neurotoxic shellfish poisoning; PD= paralytic dinoflagellate; PSP=paralytic shellfish poisoning.

Table 4.2: New York Commercial Bay Scallop Landings (1980-84)

Year	Bay Scallop Landings (000 lbs)	Landed Value ($4.91/lb) (1984 $ millions)	Landed Value (2000 $ millions)
1980	425	2.09	3.43
1981	245	1.20	1.97
1982	500	2.46	4.04
1983	165	0.81	1.33
1984	275	1.35	2.22
Average	**322**	**1.58**	**2.60**

Source: Tettlebach and Wenczel (1993)

Because bay scallop reseeding efforts have been unsuccessful, and actual bay scallop landings between 1986 and 1991 from New York waters were negligible in comparison with landings before the brown tide incident (Tettelbach and Wenczel 1993), we assumed the commercial fishery impact occurred every year during our study interval. We note that although the Kahn and Rockel study employs the theoretically correct methodology for valuing economic losses, the measure of lost surpluses is not compatible with the other data on lost sales that we have collected for this category. In this specific case, however, the measure of lost surpluses is almost exactly the same size as the measure of lost sales, [6] and we use an estimate of $3.27 million for economic impacts in this fishery.

Brown tide also may have affected oyster production in the Peconic system. The estimated commercial landings of oysters in the Peconic Estuary were about $5.84 million in 1982, plummeting to less than $14,000 per year in 1987 (SCDHS 1992). However, it is unclear, first, whether these losses were due solely to brown tide and, second, whether they occurred on an annual basis. They therefore have not been included in our tabulations.

4.1.2 ASP Impacts on Razor Clam Harvests in Washington and Oregon

Since the autumn of 1991, the occurrence of ASP has adversely affected the primarily recreational shellfisheries for razor clams in Oregon and Washington. According to the Oregon Department of Fish and Wildlife, an average of 58,000 lbs. of razor clams (at $3.65/lb.) were harvested commercially on an annual basis before closures were imposed. This implies that potential annual harvest losses are $0.21 million for the commercial market (2000 dollars). Because the

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[6] There is no reason to believe that this will always be the case. The relative sizes of lost surpluses and lost sales will depend upon the elasticities of demand and supply.

ASP events occurred during the *fall* season of 1991, we use 50 percent of this impact estimate in 1991 and the full impact estimate for 1992. In Washington State, the commercial harvest of razor clams was 23,103 lbs. in 1991.[7]

4.1.3 Alaskan Shellfish Resources

Ralonde (1998) estimates that the cost of PSP to Alaska in terms of lost value in commercial fisheries, closures of recreational shellfishing beds, and mouse bioassays is on the order of $10 million per year (1998 dollars). With respect to commercial fisheries impacts, Ralonde estimates three types of costs: geoduck processing effects, bitter crab disease (BCD) in tanner crabs (caused by dinoflagellate parasites), and a 1992 PSP event in Dungeness crabs. Ralonde calculates the 1996 lost value of geoducks due to the fact that they have to be processed to remove the viscera, where PSP toxin is concentrated. This reduces their value. Annual lost income in 1996 was $1.32 million (2000 dollars). Because the sales of geoducks in 1996 were approximately equal to the six-year average, we use the 1996 estimate of lost sales as an annual estimate for the period 1989-92 (the fishery began in 1989). Ralonde estimates the lost value in 1996 of tanner crabs due to BCD at $163,209 (2000 dollars). We assume that this is the annual lost value due to BCD during 1987-92. Finally, in 1992, a PSP event resulted in a $500,783 loss of sales in the Dungeness crab fishery (2000 dollars).

4.1.4 Ciguatera Impacts on Sales of Recreational Fish in Hawaii

Ciguatera impacts in Hawaii are estimated at $2.75 million per year (1994 dollars) based on the dollars per lb. of fish unmarketable due to ciguatera (Hokama, pers. comm., 1994). This estimate represents potential losses of retail sales from catches made mainly in sport fishing. Note that, in this case, the value of sport fishing recreation *per se* is not diminished, but the retail sale is lost. If the act of selling a caught fish is a valued part of the sport fishing experience, then the nonmarket value of recreational fishing may also be reduced. It is difficult, however, to estimate the latter impact.

4.1.5 West Coast Harvesting Delays

In California, Oregon, and Washington, Nishitani and Chew (1988) argue that shellfishing closures due to PSP have resulted mainly in harvesting delays, and not in significant financial losses. Our discussions with several New England commercial shellfishing companies suggest that short-term closures cause few operational problems and that long-term closures cause

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[7] No further commercial harvest information was received. However, we were told that most of the razor clams in Washington are found at public beaches where commercial harvests are prohibited.

financial losses only infrequently, e.g., once in every ten years.[8] However, the situation may be quite different in New England because there are many more independent clam diggers who may be affected by shellfish closures (Shumway et al. 1988). This is a complex area of impact needing further investigation. Although these other impacts may exist, the only data we have at present on commercial fishery economic impacts from HABs are due mainly to exceptional events like those presented in Table 4.1.

4.1.6 Inconclusive Impacts on Shellfish Harvests in Maine and Massachusetts

Because of inconclusive information, Table 4.1 does not present all of the potential commercial fishery losses caused by HABs during the 1987-92 period. For Maine and Massachusetts, we tried, unsuccessfully, to infer fishery impacts from a relationship between the frequency of shellfish closures due to PSP (or numbers of shellfish samples testing positive for PSP) and annual harvest values. For example, in Maine, 1988 was the year with the greatest number of HAB closures, and 1992 was the year with the least (Lewis, pers. comm., 1994). Table 4.3 presents the landed values of the four major shellfish species[9] in Maine in those two years. Lower landed values ($12.80 million) occurred in 1992 than in 1988 ($16.20 million).[10] Clearly, in Maine, shellfish closure frequency is not a good predictor of economic impacts.

Table 4.3: Landed Values of Shellfish in Maine (1988 and 1992)
(millions of dollars)

Shellfish	1988 (Constant $)	1988 (2000$)	1992 (Constant $)	1992 (2000$)
Clams	6.83	9.86	7.86	9.56
Mussels	2.17	3.13	1.02	1.24
Quahogs	1.86	2.68	1.46	1.78
Oysters	0.38	0.55	0.14	0.17
Total	**11.24**	**16.20**	**10.48**	**12.80**

Source: Lewis, pers. comm. (1994)

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[8] In Washington State, one shellfish grower stated that a worst-case scenario would involve a 3-week PSP closure, costing about $27,000 (1994 dollars), which might happen once every 10 years. An annual PSP closure, from 1 July to 1 November, of pink scallops that are marketed whole costs $58,000 (1994 dollars). However, several other commercial fishermen indicated to us that there was not much impact from PSP closures.

[9] In Maine, sea scallops must be processed at sea, and only the adductor muscles are landed and marketed. Because scallop adductor muscles do not accumulate PSP toxins, scallops are not affected by HAB closures.

[10] Total landings in these years exhibit the same pattern.

A similar situation applies to Massachusetts. The Massachusetts Division of Marine Fisheries provided us with data on the state's annual PSP tests (Whittaker, pers. comm., 1994). Table 4.4 presents the number of shellfish samples tested, the ratio of the samples with greater than 80µg/100g of PSP, and the annual commercial shellfish landing values in Massachusetts from less than 3 miles offshore for the 1987-92 period.[11] The years 1987-90 show the highest sample proportions of PSP contamination. However, a comparison with annual shellfish landing values fails to reveal a relationship between lower landed values and more frequent detection of PSP contaminated samples. Likewise, the numbers of contaminated samples alone do not indicate the severity or duration of HAB events.

Maine and Massachusetts officials record neither acreage closed to shellfishing due to HAB events nor shoreline miles affected by HAB closures. Records of shellfish closures or openings are complex, including partial extensions of closures or the reopening of already closed areas. Further, Maine has 50,000 acres of potential shellfish beds, but 90 percent of the state's total clam harvest is produced on about 10 percent of its acreage. Therefore, we conclude that it is not feasible to estimate commercial fishery impacts reliably from closure acreage or shoreline miles affected by HABs.

Finally, the co-occurrence of high coliform counts or of shellfish sanitation problems with HABs makes it difficult to factor out the economic impacts that are due solely to HAB events. For example, samples collected from certain areas in Massachusetts in 1994 showed high PSP levels, warranting shellfish closures. However, the same areas had been closed already due to high coliform bacteria levels.

4.1.7 Impacts from the Application of Health Standards

Maine oyster farmers and shellfish dealers lost $0.72 million in 1988 when their shipments of oysters tested positive for DSP by The Netherlands (Shumway 1990). However, the results of further analyses of the same shipments tested negative for DSP. Because the shipments were presumably uncontaminated, this economic impact was not included in our analyses.

4.1.8 Impacts of Wild Fish Kills

Concerns are sometimes raised in the topical literature about "indirect" commercial fishery impacts, such as wild fish kills and lost opportunities to harvest untapped shellfish resources. Wild fish kills were reported in many states (Appendix A), but for numerous reasons, measuring

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[11] The shellfish landing values exclude shrimps, crabs, squid and lobsters that are not usually affected by HABs. (Appendix E presents annual shellfish and finfish landing values for all coastal states.)

Table 4.4: Massachusetts State PSP Testing Results

Year	Species	# of Samples Tested	Ratio of Samples with PSP > 80µg	Total Commercial Landings (000s)
1987	Mussel	285	0.000	16,710
	Surf Clam	49	0.388	
	Ribbed Mussel	26	0.000	
1988	Mussel	361	0.047	14,834
	Softshell Clam	105	0.124	
	Surf Clam	44	0.386	
	Ribbed Mussel	38	0.000	
	Quahog	7	0.000	
1989	Mussel	371	0.070	11,765
	Ribbed Mussel	76	0.000	
	Surf Clam	69	0.406	
	Softshell Clam	67	0.164	
1990	Mussel	396	0.043	12,243
	Softshell Clam	86	0.116	
	Surf Clam	78	0.513	
	Ribbed Mussel	58	0.000	
1991	Mussel	348	0.003	12,008
	Surf Clam	26	0.192	
	Ribbed Mussel	24	0.000	
	Softshell Clam	20	0.000	
1992	Mussel	389	0.018	14,057
	Surf Clam	48	0.083	
	Ribbed Mussel	24	0.000	

Source: Whittaker, pers. comm. (1994)

the economic impacts of such kills is problematic. First, many of these kills involve so-called "trash" fish, which have no market value by definition. Even local officials who regularly investigate fish kill events make no attempt to estimate the economic impacts of kills of trash fish. Second, the ultimate causes of fish kills often are unclear, making it difficult to attribute them to an algal bloom.[12] Fish kills can be the result of oxygen depletion (due to high fish populations, high temperatures, or HABs), disease, bacteria, nutrients, chemical spills, or some combination of these or other factors. Potential economic impacts associated with recent fish kills (primarily menhaden) attributed to the dinoflagellate *Pfiesteria* are not included in our estimates because of the uncertainty in attributing fish kills to this organism prior to 1992. In more recent years, the economic impact from outbreaks of *Pfiesteria*-like organisms has been significant. For example, Seiling and Lipton (1998) estimated that lost sales of Maryland seafood (of all types) due to a fish kill linked to *Pfiesteria* during the summer of 1997 amounted to $45.70 million (2000 dollars). These lost sales were due entirely to the "halo effect."

4.1.9 Inconclusive Evidence of Seagrass Dieoffs in Florida

Gorte (1994) estimates that $16.10 million per year (2000 dollars) is the potential income loss due to the substantial decline in pink shrimp harvests from Florida Bay, hypothesized to be the result of a seagrass dieoff due, in turn, to blooms of blue-green algae. Using an economic multiplier, total impacts were estimated at $36.90 million. However, there is substantial uncertainty about the real causes of the seagrass dieoff and its linkage to blue-green algae (Gorte 1994; Hunt, pers. comm., 1994). Further, economic recession and foreign competition within the shrimp industry are other plausible reasons for the industry's decline. Here again, our loss estimates do not include these uncertain impacts.

4.2 Untapped Fisheries

Some currently untapped fishery "resources" may have potential values that could be realized in the absence of HAB events. Examples include the shellfish resources of coastal Alaska (e.g., Neve and Reichardt 1984) and surf clams on Georges Bank. However, in order for such "lost opportunities" to be counted legitimately as economic impacts, these fisheries must be demonstrated to be commercially viable. A plausible alternative reason for why these resources are untapped is that they are not now profitable fisheries. These issues are discussed in more detail below.

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[12] During 1980-89, NOAA found that 12 out of 22 coastal states reported more than 50 percent of all probable fish kills (NOAA 1991b). Maine, New Hampshire, Massachusetts, Pennsylvania, Delaware, North Carolina and South Carolina reported between 76 and 100 percent of probable fish kills. Each fish kill event was attributed to one or more of 20 possible causes (e.g., low dissolved oxygen, temperature, HABs, wastewater, and eutrophication, pesticides, among others). During the 1980-89 period, the numbers of fish kill events attributed at least in part to HABs were: New York (2), Virginia (2), Florida (2), and Texas (8). States like New Jersey, North Carolina, and Washington did not identify HAB as a direct cause for *any* of their fish kill events.

4.2.1 Alaska's Untapped Shellfish Resources

In Table 4.5, we report on the commercial status of Alaskan molluscan shellfish resources. Current yields are more than one million pounds per year generating approximately $4.33 million in gross revenues (2000 dollars). The status of Alaskan shellfish stocks and their commercial significance are summarized annually by the Alaska Department of Fish and Game,[13] and they have been reviewed by Foster (1997), Schink et al. (1983), and Jewett and Feder (1981). All commercial shellfish except for the Pinto abalone, chitons, and limpets are threatened by PSP contamination (Foster 1997). Recently, some species have tested positive for ASP. Yields of razor clam, weathervane scallop, and geoduck (see below) are processed to remove portions of the animal that may be toxic. The Pacific oyster, blue mussel, and Pacific littleneck clam are cultured species for which bioassays are conducted as they are produced. Black katy chitons, fat gapers, gumboot chitons, and limpets are all subsistence fisheries for which there is no major commercial market. Historically, significant quantities of butter clams (1946) and cockles (1962) were produced off the Alaskan coast. More recently, however, only minor harvests have taken place, and, although small markets for these species exist on the west coast of the United States, it is not clear that historical levels of production could be commercially viable (Ostasz, pers.comm., 2000, 1994). A 1977 NMFS survey of the southeast Bering Sea revealed significant quantities of great Alaskan tellin clams (Lutz and Incze 1979; Nelson *et al.* 1979), but there is no known market for tellin in the United States.

The 1977 NMFS survey also revealed potentially exploitable quantities of the Alaskan surf clam (*Spisula polynyma*) in the Bering Sea. Hughes and Bourne (1981) estimate an annual maximum sustainable yield (MSY) of 25,017 metric tons for this resource. The Alaskan discovery came at a crucial time in the U.S. surf clam market, as the mid-Atlantic surf clam (*Spisula solidissima*) resource had just suffered a steep decline due to an oxygen depletion event in the New York Bight, and the price of surf clams tripled during 1976 and remained high for the next ten years as the resource recovered. In 1979, Lutz and Incze (1979) valued the annual potential sustainable yield of surf clams at $28-47 million (2000 dollars). However, only small quantities of Alaskan surf clams have been harvested since the 1977 stock assessment was conducted.

The reasons for the lack of a viable Bering Sea surf clam fishery are not completely clear, but several hypotheses have been put forward. First, some of the surf clam resource has tested positive for PSP. Neve and Reichardt (1984) argued that persistent PSP was largely responsible for the non-exploitation of this resource. However, Ostasz (pers.comm., 2000), citing Hughes and Nelson (1979), notes that only a small proportion (2 out of 185 samples) had detectable levels of PSP toxin in 1978, and no samples tested positive for toxin in 1977. Because Alaska

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[13] Shellfish statistics are updated annually at http://www.cf.adfg.state.ak.us/geninfo/shellfsh/shelhome.htm#species.

Table 4.5: Status of Alaskan molluscan shellfish resources

RESOURCE	GENUS/SPECIES	LOCATION	YEAR	HARVEST	PRICE	REVENUE	PSP	STATUS	CITE
				lbs	$/lb	$m	Threat		
Butter clam	*Saxidomus giganteus*	Southeast	1946	1,763,698			PSP	minor 1995-96 harvest	Nishitani and Chew (1988)
Cockle	*Clinocardium nuttallii*	Southeast	1962	1,302,932			PSP	minor 1995 harvest	Nishitani and Chew (1988)
Pacific Oyster	*Crassostrea gigas*	Southeast, Southcentral	1996-98	874,318	0.41	0.36	PSP	cultured (bioassayed)	ADF&G (1999)
Razor clam	*Siliqua patula*	Cook Inlet	1995-99	339,025	0.16	0.05	PSP	processed (toxin removed)	ADF&G (1998); McNair (pers. comm., 2000)
Weathervane scallop	*Patinopecten caurinus*	Yakutat	1999	280,000	3.00	0.84	PSP	processed (toxin removed)	ADF&G (2000)
Weathervane scallop	*Patinopecten caurinus*	Kodiak	1996	270,000	6.00	1.62	PSP	processed (toxin removed)	ADF&G (1998)
Geoduck	*Panopea abrupta*	Southeast	1995-99	193,491	3.38	0.65	PSP	processed (toxin removed)	ADF&G (2000); McNair (pers. comm., 2000)
Pinto Abalone	*Haliotis kamtschatkana*	Cape Spencer to Yakutat		50,000	9.12	0.46			Imamura (1994)
Pacific littleneck clam	*Protothaca staminea*	Southeast; Kachemak Bay	1995-99	45,331	2.69	0.12	PSP	cultured (bioassayed)	ADF&G (1999); McNair (pers. comm., 2000)
Weathervane scallop	*Patinopecten caurinus*	Cook Inlet	1996	30,000	7.00	0.21	PSP	processed (toxin removed)	ADF&G (1998)
Mussel	*Mytilus edulis*	Southeast, Southcentral	1996-98	4,674	2.23	0.01	PSP	cultured (bioassayed)	ADF&G (1999)
Alaska surf clam	*Spisula polynyma*	Bristol Bay	1985		0.54	0.00	PSP	minor 1985 harvest	Ralonde (1998); Hughes and Bourne (1981)
Black katy chitons	*Katherina tunicata*	Southeast	1985					subsistence fishery	Foster (1997)
Fat gapers	*Tresus capax*	Southeast	1985				PSP	subsistence fishery	Foster (1997)
Gumboot chitons	*Cryptochiton stelleri*	Southeast	1985					subsistence fishery	Foster (1997)
Limpets		Southeast	1985					subsistence fishery	Foster (1997)
Tellin	*Tellina lutea*	Bristol Bay	1985				PSP	no fishery	Lutz and Incze (1979)

has not “classified” the Bering Sea according to NSSP standards, harvesting the resource is currently infeasible.[14]

A second plausible reason for the lack of production may be that the fishery is not commercially viable (Foster 1997). Certainly, production of surf clams at the MSY level is likely to drive price down in the U.S. surf clam market, thereby decreasing the profitability of the fishery or even precluding its initiation. Further, the structure of the market may present an entry barrier into this fishery. With respect to the mid-Atlantic surf clam fishery, Weninger (1998:755) states that: “[t]he perishable nature of the clams, scheduling of processing activities, and the need to coordinate with downstream buyers requires tight vertical coordination between fishers and processors." Without the establishment first of a costly processing infrastructure, and considering the difficulty of distributing product from a remote location, it may be difficult for a surf clam fishery to get established in Alaska. Finally, Ostasz (pers.comm., 2000) suggests that seasonal closures might be imposed on a potential surf clam fishery to protect juvenile spawning grounds for King crab. It is possible that the timing or area coverage of a closure would increase the cost of surf clam fishing to levels that might not support a fishery.

Finally, there has been concern expressed over the potential impacts on walrus stocks from the harvesting of Alaskan surf clams, which are an important food source for walrus (Stoker 1979 as cited by Foster 1997). This concern might express itself in opposition from environmental interests should a commercial operation be initiated. The Alaskan Eskimo Walrus Commission has the responsibility for protecting surf clam resources in walrus habitat (Ostasz, pers. comm. 2000).

Even in the face of uncertain business factors and potential environmental opposition, reports continue to surface stating that a $50 million Alaskan surf clam resource is precluded by HABs. We do not have critical information on the cost of producing Alaskan surf clams, but we can hazard a rough estimate of the economic impacts associated with a hypothetical Bering Sea fishery. To accomplish this, we make the following assumptions:

- The only obstacle to commercialization of the Alaskan surf clam resource is the potential presence of shellfish poisoning (PSP or ASP);
- The Alaskan surf clam is a close substitute for the Atlantic surf clam and will compete in the same market;
- Production of the Alaskan (and Georges Bank) resources at estimated MSY levels is likely to affect the price of surf clams in the U.S. market (by driving it down);

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[14] Classification might occur if significant commercial interest arose. Foster (1997) notes that the turnaround time on the mouse bioassay from Alaska’s one shellfish testing lab may be too long for a resource that quickly spoils.

- There is no expansion of existing demand such as might occur, for example, through the opening of an export market;

- An Alaskan surf clam fishery is financially viable and will produce at MSY;

- For the years 1989-1992, an Atlantic surf clam fishery on Georges Bank is financially viable and produces at the 1988 level of yield;

- Fishermen in the mid-Atlantic fishery will continue to harvest the same amount of Atlantic surf clams as before.

If we multiply the current market price times the hypothetical yield of Alaskan and Georges Bank surf clams to obtain "lost gross revenues" due to PSP, the value of yields of Alaskan, Georges Bank, and mid-Atlantic surf clams will all be too high. To arrive at a more realistic price, we adapt and modify the specification embodied in a demand model for the mid-Atlantic surf clam fishery which was developed by Armitage (1985).[15] We fit the model using monthly data from 1991-98 to estimate updated parameters that describe how the price of surf clams varies with the quantity supplied to the market (and other related variables).[16]

The results of this analysis are presented in Table 4.6. Using annual yield and annual average price data for 1987-92, we estimate the price of surf clams [column (D)] that would have resulted from the production of mid-Atlantic surf clams at historical levels, Alaskan surf clams at the MSY level, and Georges Bank surf clams at the 1988 level (the latter only for the years of closure: 1989-92). We then use this price to calculate the potential "lost" gross revenues for both Alaskan [column (F)] and Georges Bank [column (G)] surf clams due to HABs closures.

Note that the "gain" to the Alaskan and Georges Bank surf clam fisheries actually results in a decline in gross revenues in the mid-Atlantic fishery (compare column [E] with column [C]). In order to calculate the "net" contribution to gross revenues in the *national* surf clam market that results from expanded supply, we apportion[17] the reduced gross revenues in the mid-Atlantic

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[15] Armitage's (1985) model is developed with quarterly data from 1976 to 1980. Note that one of our assumptions assumes that industry structure remains unaffected. As price declines, we might expect some marginal fishermen to exit the mid-Atlantic fleet. With a change in fleet size, it is possible that less product will be harvested in the mid-Atlantic, thereby buoying the price. Further, we do not know the cost structure for an Alaskan operation. Another important consideration that we ignore here is the radical change in the mid-Atlantic's management regime in 1990 from a time-restricted, quarterly TAC regime to an ITQ regime. As a consequence, the application of the model to the pre-1990 surf clam market may be questioned.

[16] Armitage's model is an ex-vessel "price prediction" model that does not factor out supply effects explicitly. The model tests the hypotheses that surf clam price is a function of surf clam landings, the demand for ocean quahogs, the demand for hard clams, and the demand for oysters. The modified model specification and the parameter values used here are available from the authors upon request.

[17] The decrease in mid-Atlantic revenues is apportioned using the relative ratio of yield in each fishery. For example, the Alaskan share is equal to 0.97 = 25,017mt/(25,017mt + 711mt).

Table 4.6: Estimated “Net” Gross Revenues Arising from Opening the Alaskan and Georges Bank Surf Clam Fisheries

(2000 dollars; gr rev = gross revenues)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	ACTUAL MID-ATL LANDINGS	ACTUAL MID-ATL PRICE	ACTUAL MID-ATL GR REV	ESTIMATED U.S. PRICE	ESTIMATED MID-ATL GR REV	ESTIMATED ALASKA GR REV	ESTIMATED GEORGES BANK GR REV	ESTIMATED TOTAL U.S. GR REV	NET ALASKAN GR REV	NET GEORGES BANK GR REV
1987	60,743,928	0.69	42,067,532	0.41	25,044,815	22,739,704		47,784,520	5,716,987	
1988	62,113,500	0.66	41,184,360	0.42	26,204,755	23,268,262		49,473,017	8,288,657	
1989	67,071,920	0.63	42,290,924	0.39	26,341,452	21,660,517	615,432	48,617,401	6,151,691	174,786
1990	70,750,886	0.58	41,301,457	0.32	22,700,343	17,695,807	502,784	40,898,934	-391,402	-11,121
1991	65,722,147	0.55	36,272,435	0.36	23,909,371	20,064,403	570,083	44,543,856	8,042,902	228,520
1992	72,841,527	0.53	38,486,668	0.37	26,920,663	20,383,397	579,146	47,883,206	9,136,933	259,604
AVG									6,157,628	162,947

fishery across both the Alaskan (column [I]) and Georges Bank column [J]) fisheries. Note that this apportioning is conducted purely for accounting purposes *at the national level.* For example, in 1987, the gross benefit *to Alaska* of a surf clam fishery is roughly $23 million, but the contribution of an Alaskan fishery to the nation, given that demand is downward sloping, is only about $6 million.

In 1990, the decline in gross revenues in the mid-Atlantic fishery is so substantial, that the "net" contribution to total U.S. gross revenues from landings in the other fisheries is negative. During the study period, the average HABs-related loss in gross revenues to the hypothetical Alaskan surf clam fishery is approximately $6.16 million and to the hypothetical Georges Bank surf clam fishery is $0.16 million (2000 dollars). We believe that these are much more realistic estimates than the $50 million that is typically discussed.

4.2.2 Georges Bank Surf Clam Fishery

The Georges Bank surf clam fishery has been closed since 1989 due to high PSP levels. Assuming this is a viable commercial fishery, the opportunity costs of closing the fishery could be viewed as an estimate of the economic impacts of HABs. In 1990, the combined New England and mid-Atlantic surf clam quota allowed by NMFS was 230 metric tons, valued at only $2.94 million (2000 dollars). Note that because individual surf clam quotas are not site-specific, fishermen can switch at low cost to other regional locations, e.g., offshore New Jersey. As explained in section 4.2.1, we estimate average annual economic impacts to be $0.16 million (2000 dollars).

4.2.3 Georges Bank Roe-On Scallop Fishery

The traditional offshore scallop fishery in the U.S. sector of Georges Bank has not been affected by HABs because the product, the scallop adductor muscle, does not concentrate PSP toxins. However, the potential may exist for the development of a "roe-on-scallop" fishery (adductor muscle with the gonad attached), because this product is highly regarded in much of the world. The roe can accumulate PSP toxins, so such a fishery would be affected by the presence of the toxins. A fishery for roe-on-scallops has existed in the Canadian sector of Georges Bank since the late 1980s. The fishery is relatively small, involving about 5,000 lbs. of roe-on-scallop landings per week (K. White, pers. comm., 1998). The fishery was closed from about 1992 to 1994 because of high levels of PSP toxins. The roe-on scallops are not marketed in Canada but are sent overseas, bringing in substantially more revenue per pound than the adductor muscle alone does (K. White, pers.comm., 1998).[18]

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[18] The unit price of the roe-on product is about $C15/lb overseas. In Canada, the exvessel value of the adductor muscle alone is about $C 8-9/lb (K. White, pers. comm., 1998).

It is unknown to what extent a similar roe-on-scallop fishery would be commercially viable in the United States sector of Georges Bank. There is insufficient information about the international demand for the product or of the logistics and expense of toxin testing protocols. We therefore do not consider it meaningful to assess the economic impact of lost opportunities in this fishery because of the lack of quantitative information. Nevertheless, it is conceivable that shellfish poisoning is restricting the development of a U.S. roe-on-scallop fishery.

4.3 Major HAB Events in Other Years

This study focused on the years 1987-92, yet there were a number of significant events in other years that demonstrate the magnitude of the impacts that are possible. For example, in 1976, New Jersey suffered an extensive oxygen depletion event in which HABs were implicated in part. A confluence of oceanographic, hydrologic, and meteorological factors led to a bloom of the dinoflagellate *Ceratium tripos*, which resulted in anoxic conditions and the formation of hydrogen sulfide in the bottom waters of the New York Bight. The bloom affected sedentary commercial stocks of surf clams, ocean quahogs, sea scallops, and some finfish and lobster. Lost sales from harvests during 1976 and for five to seven years into the future (for scallops and surf clams respectively) were estimated. The largest impacts by far occurred in the surf clam market. Impacts in the downstream processing and marketing sectors were estimated using a multiplier of 2.5. Total lost sales in all sectors combined were estimated to be $1.33 billion in 2000 dollars (Figley et al. 1979).

In September 1980, the entire Maine coastline was closed to shellfishing because of a bloom of the dinoflagellate *Alexandrium tamarense*, a source for PSP toxins. Harvest losses from this event were estimated at $5.04 million, and total economic impacts were estimated to be $15.10 million, using a multiplier of 3 (2000 dollars). Also in 1980, California, Oregon, and Washington closed oyster harvesting for one month due to PSP toxicity, resulting in losses to commercial oyster growers in these states of $1.31 million (Nishitani and Chew 1988). In 1986, a red tide of *Gymnodinium breve* event in Texas caused the loss of $2.22 million in oyster production, resulting in estimated economic impacts of $6.00 million (2000 dollars) (Texas Shores 1987).

In 1997, a bloom of *Pfiesteria* occurred in several Chesapeake Bay tributaries. The bloom resulted in the deaths of from 30-50,000 menhaden. After medical testing of fishermen who complained of an array of physical and neurological problems, the Governor of Maryland acknowledged the human health risk associated with *Pfiesteria* and closed several Chesapeake tributaries to recreation and fishing (Bowman 1997). Although the state later spent half a million dollars on a promotional effort to counteract the scare, demand for seafood from the state of Maryland shrank significantly during the autumn of 1997. Lipton (1999) estimates $45.70 million in lost seafood sales to Maryland producers that can be attributed directly to the 1997 *Pfiesteria* scare (2000 dollars).

5 RECREATION AND TOURISM IMPACTS

In 1991, a federal government study estimated that saltwater anglers spent an average of $562 per angler, totaling $5 billion (1991 dollars) for travel, food, lodging and equipment (DoI and DoC 1993, Appendix D). When compared with the total U.S. domestic landings of commercial finfish and shellfish ($3.3 billion in 1991), total recreational expenditures can be seen to be 67 percent greater than commercial fish landings. However, to date, the economic impacts of HABs on recreational and tourism activities have been given little attention relative to the impacts on commercial fisheries.

Although many experts argue that the impacts of HABs on recreation and tourism are important and potentially large, there are few available data describing the size of the impacts (Table 5.1). Our estimates of the economic impacts on recreation and tourism during the 1987-92 period range from zero to $29.30 million. The annual average is $6.63 million.

Table 5.1: Recreation and Tourism Impacts
(2000 $U.S. millions)

Year	Incident	Type	State	Estimated Impacts	Annual Total Estimated Impacts
1987	tourism and recreation impacts to a coastal community (red tide)	NSP	North Carolina	28.32	29.30
1988					0.00
1989					0.00
1990					0.00
1991	Recreational shellfishing for razor clams Recreational shellfishing for razor clams	ASP ASP	Oregon Washington	1.05 0.66	1.71
1992	Recreational shellfishing for razor clams Recreational shellfishing for razor clams	ASP ASP	Oregon Washington	2.04 6.72	8.76

5.1 The 1987 North Carolina Red Tide Event

The overall impacts from a 1987 HAB event in North Carolina have been "conservatively" estimated at $37.57 million (2000 dollars) (Tester et al. 1988). This estimate includes neither the public health impacts nor monitoring and management costs. Because the losses to commercial fish harvests from this incident were estimated at $8.27 million, we can attribute the remaining $29.30 million to recreation and tourism impacts. The estimated tourism and recreation impacts of the incident amounted to only 1.9 percent of the $1.52 billion (2000 dollars) generated by combined hotel, lodging, amusement and recreation services in the entire state of North Carolina in 1986.[19] Nevertheless, we expect that the ratio of economic impacts to measures of county productivity in the four impacted coastal counties is much larger. However, as tourists redirected their vacation destinations, negative impacts that occurred in these four counties are likely to have been counterbalanced by positive impacts in other counties, in North Carolina and elsewhere, thereby mitigating aggregate impacts at the state or regional level.

5.2 The 1991-92 Washington and Oregon ASP Event

Another major HAB event that affected recreation and tourism activities occurred in Oregon and Washington during 1991-92. In October 1991, these states closed their primarily recreational razor clam fisheries because of ASP contamination. In Oregon, prior to the closures, roughly 67,000 trips per year were taken for recreational shellfishing of razor clams (Radke, pers. comm., 1994). On average, recreational shellfishermen spend $30.51 per trip (2000 dollars). Therefore, we estimate the 1992 economic impacts of the razor clam shellfish closure to be $2.04 million. We assume that the 1991 impacts were a little more than one-half of this amount, $1.05 million, because the onset of ASP contamination occurred during the fall of 1991.

In Table 5.2, we present the numbers of recreational shellfishing trips in Washington State for razor clams during the spring and fall seasons before and after the outbreak of ASP (Ayres and Simons 1993, 1992). The number of trips in the fall of 1991 fell by 21,333 compared with the three-year average prior to the ASP event. In 1992, the combined number of trips made during the spring and fall seasons was smaller by 220,666 compared with the three-year average. Using an estimated average per trip expenditure of $30.51 for recreational shellfishing, we estimate the impacts on recreation and tourism to be $0.66 million and $6.72 million in 1991 and 1992, respectively.

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[19] Appendix C presents, for each coastal state, gross state product (GSP) and the value of output from several industrial sectors within that state during 1985-90 (Trott et al. 1991).

Table 5.2: Washington State Recreational Shellfishing Trips for Razor Clams
(before and after October 1991 ASP event)

Season	Fall	Spring
1988-89	43,000	195,000
1989-90	55,000	204,000
1990-91	32,000	274,000
Average (88-91)	**43,333**	**224,333**
1991-92	*22,000	0
1992-93	47,000	136,000
1993-94	60,000	--

*Fall 1991 season was cut short.
Source: Ayres and Simons (1993, 1992)

5.3 Recreational Impacts - Large but Uncertain

Many experts consider the economic impacts of HABs on commercial fisheries to be minor in contrast with the size of the impacts on recreation and tourism. This is believed to be the case in Florida, where Habas and Gilbert (1975) estimated the economic damage to the tourist industry of a summer 1971 *Gymnodinium breve* red tide event at more than $68 million (in 2000 dollars). *Gymnodinium* blooms have occurred after 1971, but there have been no attempts to estimate economic impacts. The most significant impacts occurred in the hotel, restaurant, amusement, and retail sectors. As with the North Carolina red tide event, we need to be careful in interpreting these damage estimates. Undoubtedly some tourists spent their monies at other tourist destinations in Florida or other states.

When kills of “trash” fish result from an HAB, there is no commercial fishery impact, but dead fish can substantially reduce the recreational “experience” of visitors to these beaches. In Texas, a severe HAB event was reported during the period from August to October 1986. Most of the dead fish from this event were either trash or “underutilized” fish, but many of these washed up on beaches, where they decayed. According to Texas Shore magazine (1987), this event resulted in economic impacts on tourism and seafood sales. However, the gross impact was minimized because the economy of many Texas coastal communities was already depressed. In fact, sales tax proceeds from ten affected coastal counties for the months affected by the HAB indicate only small overall impacts when compared with tax proceeds the year before.

5.4 Laguna Madre Brown Tide

Although we expect some level of economic impact from an HAB event, the anecdotal evidence sometimes can be contradictory. As an example, from May 1990 until recently, a brown tide developed and then persisted for over 7 years in the Laguna Madre, along the southern coast of Texas. Some professional sport-fishing guides reported that they lost many customers, but others say that customers are still catching fish by changing fishing methods to cope with a change in the water's transparency level. (Water was clear before the outbreak, so “sight casting” was possible). The Texas Parks and Wildlife Department reported that their monthly fish stock assessments indicate the same abundance of adult and juvenile fish in the Laguna Madre when compared with the situation prior to the brown tide, and their sport harvest surveys reveal unchanged levels of sport fishing catches (Spiller, pers. comm., 1994). The Laguna Madre system had suffered two unusually hard freeze seasons, causing widespread fish kills prior to the onset of the brown tide. Sport fishermen may have bypassed the Laguna Madre because of poor fishing results at those times.

5.5 Property Value and Recreational Impacts of Macroalgae

In Massachusetts, local residents expressed several different opinions about the economic impacts of a slimy, dark-brown macroalgae, *Pillayella litoralis*. Since 1987, the recurrent accumulation of *Pillayella* in Nahant Bay and Broad Sound has been attributed to eutrophication of Massachusetts Bay by the press and the general public, but this may be more easily related to a unique hydrographic mechanism which carries this alga to shore and concentrates it on one particular shoreline location. *Pillayella*’s abundant growth interferes with swimming, and it generates a sulfurous, "rotten-egg" odor as it decomposes on beaches. The property values of houses in the area could be reduced by the existence of these algae on beaches and their smell. However, this effect was both variable and uncertain. One Nahant realtor told us that prices of some of the houses she sold were depressed because of the algae. In particular, she speculated that a house that sold for $300,000 could have been worth $325-350,000 if there had been no *Pillayella* problem (1994 dollars). A second realtor did not think property values were affected at all, and a third believed that there was a negative effect, but that because the housing market had been depressed for some time, the actual sales data do not show an impact.

Macroalgae may also negatively affect recreational activities. One local Nahant resident told us that the presence of *Pillayella* resulted in no differences in beach attendance rates. However, observations of identical numbers of beach-goers does not necessarily imply that there has been no recreational impact, because when beach or fishing conditions deteriorate, each recreationist’s personal “enjoyment” may decline. Therefore, it is important to know by *how much* recreationists value certain environmental conditions, instead of focusing on only the participation rate.

Efforts to measure these types of recreation and tourism impacts must be undertaken at the local level because local environmental and socioeconomic conditions are critical determinants of changes in recreational benefits. Moreover, in their valuation attempts, analysts also should incorporate the existence of substitute beaches or other recreation areas where tourists can visit. Even if certain areas are affected by HABs adversely, recreationists may be able to visit other nearby areas that offer similar recreational amenities. In such a case, regional economic impacts may be minimal.

6 MONITORING AND MANAGEMENT COSTS

In Table 6.1, we present our findings about the costs of monitoring and managing HABs. Annual average monitoring and management costs total $2.09 million (2000 dollars) in the United States. We were able to obtain annual estimates of monitoring and management costs from twelve states: Alaska, California, Connecticut, Florida, Maine and New Hampshire (combined), Massachusetts, North Carolina, New Jersey, New York, Oregon, and Washington. Many states experiencing HABs, such as Texas, do not have a regular monitoring program for PSP or HABs. It is often the case that water monitoring tasks, including PSP testing, are spread across different divisions of state government, making it difficult to collect data on costs (Langlois, pers. comm., 1994). Further, monitoring activities for both HABs and other water quality testing, such as shellfish sanitation, often are conducted by the same experts. Consequently, it is difficult to factor out those costs related specifically to HAB monitoring and management.

In addition to the annual monitoring and management costs incurred by coastal states, we report other categories of costs in Table 6.1. For example, in Massachusetts, BlueGold Mussels, Inc. spent approximately $6,000 per year (1994 dollars) conducting PSP tests on their own shellfish products. We also present other estimates of the costs of monitoring or management related to one-time or infrequent events including: survey and investigation costs for two specific HAB events in New Jersey (Olsen, pers. comm., 1994); the cost estimate for a 3-month NSP event on Florida's west coast (Roberts, pers. comm., 1994); and the ASP tests during the spring of 1994 in Washington (Simons, pers. comm., 1994).[20]

Our estimate for monitoring and management costs in Florida includes the annual costs of beach cleanups on the southwest coast of Florida. These costs are currently incurred primarily by each of the eight counties along that coast. We have collected recent (1995-97) estimates of the costs of beach cleanups for Sarasota County (Conn, pers. comm., 1998). These costs average $56,592 per year (current dollars), and they apply to the cleanup of dead fish due to HAB events and to the collection and disposal of red seaweed that washes up during storms. A significant portion of the annual costs is the tipping fee. We divide this average cost by the number of miles cleaned (17.5) in Sarasota County to develop a per mile cleanup cost. We assume that approximately 50 miles of the 200-mile southwest coast of Florida are cleaned each year, accounting for the patchiness of red tide events and the difficulty of accessing certain areas of the coast. The result is an estimate of the cost of beach cleanups for HAB events and washed up seaweed of about $162,500 per year (1998 dollars). Further research will allow us to refine that estimate. Note that Habas and Gilbert (1975) estimated the cleanup costs for a 1971 red tide event to be approximately $755,211 in 2000 dollars.

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[20] This expenditure was for the spring season only. Apparently a budget shortfall precluded further ASP tests in the fall season of 1994 (Simons, pers.comm., 1994).

Table 6.1: Annual Average Monitoring and Management Costs

(2000 $U.S. thousands)

State	**Type of Cost**	**Annual Average Cost ($000)**
Alaska	Estimated fees for PSP and ASP costs	320.74
California	Annual monitoring	212.73
Connecticut	Annual monitoring	10.11
Florida	Personnel salaries and associated overhead for monitoring and bioassaying for a 3-month *Gymnodinium breve* event on west coast; estimated costs for beach clean-ups during each year	183.59
Maine/New Hampshire	Annual PSP monitoring	291.61
Massachusetts	Annual monitoring; Annual private PSP monitoring by BlueGold Inc. (400 samples annually at $15 per sample)	57.79
New Jersey	A series of three tests for annual red tide monitoring at $100 per test; individual response investigations by four separate agencies for a Jun-Aug 1988 algal bloom; intensive follow-up survey conducted in 1989 for the Jun-Aug 1988 bloom; individual response investigations by two agencies for a July 1992 algal bloom	30.30
New York	Annual monitoring	319.10
North Carolina	Annual monitoring	34.84
Oregon	Annual monitoring	96.26
Washington	Annual monitoring	531.83
TOTAL		**2088.89**

7 CONCLUSIONS AND FUTURE RESEARCH NEEDS

7.1 Annual Aggregate Economic Impacts

Table 7.1 (which reproduces Table ES-1), is a compilation of our estimates of the annual aggregate economic impacts (in millions of 2000 dollars) of HABs in the United States during the 1987-92 period. For each of the four main types of impacts, we present both the ranges of annual estimated impacts during the 1987-92 study period and average annual estimated impacts. Public health impacts are the largest component, representing about 45 percent of total average impacts at more than $22 million annually. Impacts from ciguatera poisonings are the largest element of those public health impacts. Commercial fisheries impacts are the next largest component, representing 37 percent of total average impacts at more than $18 million annually. Recreation/tourism impacts account for 13 percent of total impacts at nearly $7 million annually. Monitoring/management costs represent only 4 percent of the total at more than $2 million annually. It is important to note that expenditures made to improve monitoring and management likely resulted in decreases in impacts in the other categories.

We also present an estimate of capitalized impacts. Assume that our estimates of impacts will occur on an annual basis over the next 15 years. Discounting these annual losses at a rate of 7 percent and summing the discounted losses results in an estimate of capitalized impacts. Our estimate of 15-year capitalized average impacts is $449 million.

During the 1987-92 period, total annual impacts fluctuated widely (except for monitoring/management costs). This reflects the irregular occurrence of HAB events, which in turn vary dramatically with respect to the magnitude of impacts. We expect that coastal communities and industries are able to manage recurrent (i.e., expected or “predictable”) outbreaks reasonably well, thereby limiting their economic impacts (Shumway et al. 1988). However, outbreaks of unexpected or unusual blooms may tend to cause more severe economic impacts (Bicknell and Walsh 1975; Egan 1990; Tester et al. 1988).

7.2 Reasons Why Our Estimates are Conservative

The estimates reported here represent a preliminary approximation of the economic costs to the United States from the occurrence of HABs. The fact that these estimates are uncertain or approximate is not due to lack of effort, but rather to the difficulty in assigning impacts to many of the events that occurred – due to lack of information and even to a lack of knowledge as to how to quantify certain impacts. Due to reporting inadequacies and the large size of the US coastline, the HAB events on which this analysis is based are a subset of all outbreaks that occurred during the 1987-92 window. Consequently, our aggregate economic impact underestimates the actual impacts. A second qualification is that, although we report on economic

Table 7.1: Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States

(Estimate is of 1987-1992 period, reported in 2000 dollars)

	Low	High	Average	% of Total
Public Health	$ 18,493,825	$ 24,912,544	$ 22,202,597	45%
Commercial Fishery	$ 13,400,691	$ 25,265,896	$ 18,407,948	37%
Recreation/Tourism	$ -	$ 29,304,357	$ 6,630,415	13%
Monitoring/Management	$ 2,029,955	$ 2,124,307	$ 2,088,885	4%
TOTAL	$ 33,924,471	$ 81,607,104	$ 49,329,845	100%
15 Year Capitalized Impacts (discounted at 7%)	$308,981,162	$743,270,485	$449,291,987	

impacts, we did not use economic multipliers. Thus, our estimates reflect only the direct effects of HAB events, ignoring indirect and induced effects on other sectors of the economy. Again, this conservative approach leads to underestimates of the true impact.

Human sickness and death from eating tainted seafood results in lost wages and work days and pain and suffering. Costs of medical treatment and investigation are also an important aspect of the economic impact caused by such events. We know that a substantial number of illnesses caused by HABs remain unreported. In the absence of a reliable method for estimating the actual number of illnesses, we adopted conservative "rule-of-thumb" factors from several experts in the field. Further, we used estimates developed by Todd of the costs of shellfish and ciguatera poisoning -- estimates that are smaller, by an order of magnitude, than generic estimates of nonfatal illness costs emerging from studies of job risks.

Our public health impact estimates are dominated by ciguatera illness and treatment costs, but these estimates are low because ciguatera poisoning also occurred outside of the areas we surveyed as a result of exports of tropical fish to other jurisdictions. In addition, we have been unable to include either the costs of insurance to cover potential ciguatera-caused liabilities or the court costs associated with ciguatera-related litigation.

Commercial fisheries impacts underestimate true losses due to HAB events because they do not include PSP closures in several states, including Maine and Massachusetts, where it was not possible to document the acreage closed or the value of the resource that was not harvested during PSP outbreaks. These states are examples of the case where the price of shellfish may <u>increase</u> when landings are lowered due to closures. Indeed, the economic impact estimate from harvesting closures (basically the increased value of output), would appear to be positive—a counterintuitive result. Although some shellfishermen may benefit from price increases, consumers unambiguously lose. These losses are not included in our economic impact estimates, because once again, it is difficult to quantify them. Furthermore, our estimates do not include the costs of wild fish kills, because the value of those fish is not known in most cases.

Another factor that leads to an underestimate of impacts is the economic loss from blooms of *Pfiesteria* or *Pfiesteria*-like organisms that have not been included in our totals. Although recent *Pfiesteria* blooms have been shown to have major economic halo effects in Maryland following an outbreak in 1997 (Seiling and Lipton 1998), the organism had not been identified during the early portion of our study period, and even after it was first linked to massive fish kills, no estimates could be obtained of the economic losses associated with those events. In part this reflects the difficulty in attributing causality to past fish kills and in assigning economic value to wild fish.

Yet another conservative aspect of this study is that some currently untapped fishery resources have values that might be realised in the absence of HAB events, but such estimates are not included here. Examples include some shellfish resources of coastal Alaska, which are permanently quarantined due to persistent toxicity and the logistics of sampling distant or remote resources (Neve and Reichardt 1984), and a potential roe-on scallop fishery on Georges Bank.

Finally, although many experts argue that the impacts of HABs on recreation and tourism are important and potentially large, there are few available data describing the size of the impacts. For example, reduced tourism and lowered residential real estate values on the Gulf Coast of Florida are two types of impacts that are likely to be large but for which we currently have no data.

7.3 Information Needs

In addition to economic impact estimates, we made several important findings about the current state of available information and the need for improvements in the data collection process. First, the reporting practice of HAB events needs to be expanded and the format formalized. At present, information about HAB events is fragmentary and incomplete in its coverage. HAB data are compiled on an annual basis by the U.S. National Office for Marine Biotoxins and Harmful Algal Blooms at the Woods Hole Oceanographic Institution. These data are maintained by that office, and are also supplied to the ICES/IOC Working Group on Harmful Algal Bloom Dynamics, which has entered them into an international database called HAEDAT (Harmful Algal Events Database), maintained by the IOC HAB Science and Communication Centre in Vigo Spain. However, the data collection effort within the different reporting regions of the US relies on volunteer efforts by academic and government scientists as well as government officials, and thus tends to be uneven in coverage and detail. Efforts are underway to standardize the data collection process, but even with those changes, it is clear that these individuals cannot provide the type of information needed for economic impact assessment. At the least, the duration, affected acreage or shoreline length, average toxicity levels, and values of affected coastal resources should be documented for each bloom in order to describe the overall economic significance of the incident. In addition, local and state governments should place much higher emphasis on quantification of economic impacts. Economic impacts are usually specific to local environmental and socioeconomic conditions, and local officials are therefore the ones who need to compile the information which can later be analyzed by economists. Until local governments become capable of supplying site-specific impact information for each bloom incident, truly comprehensive and detailed national level aggregation of such impacts cannot be realized.

Second, we note that some economic information is available on economic impacts to fisheries resources or to human populations exposed to HABs, but there is a significant lack of available information about recreation and tourism impacts. This could be a significant but highly episodic factor that is presently underestimated in our study.

Third, the causes of economic impacts and the degree of their uncertainty should be included in any study of economic impacts. For example, it may be premature to attribute the economic impacts solely to a specific HAB, because there are often other possible explanations for mortality events. Finally, economic factors that are used to generate the impact estimates should be reported. These factors include whether or not an economic multiplier is used; local economic recession or prosperity trends; and foreign and domestic seafood competition factors.

7.4 Overview

Here we offer the first effort to compile an estimate of the economic impact of HABs in the US. The data generated are of interest and use, but it is also of note that the process of collecting, compiling, and analyzing that data revealed areas where changes are needed. This includes changes in the reporting process, as well as the development of new approaches to the assignment of impacts to certain types of events or situations (e.g., the evaluation of unexploited fisheries, or the losses associated with quarantine or harvesting restrictions).

Overall, the economic impacts from HABs are diverse and large. Even with the highly conservative treatment given the impacts in this study, the annual costs are significant. Average annual costs also tend to mask the significance of individual HAB events, some of which greatly exceed the annual average for the entire country. Perhaps more importantly, HABs are recurrent, and show signs of increasing as the number of toxic and harmful algal species grows and as our reliance on the coastal zone for aquaculture, commerce and recreation expands. Prudent investment in research and monitoring can do much to reverse this trend and to reduce the annual impacts.

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APPENDIX A

Harmful Algal Bloom Incidents

This Appendix is a summary of harmful algal bloom incidents reported informally from coastal states to the National Office for Marine Biotoxins and Harmful Algal Blooms at the Woods Hole Oceanographic Institution for the 1987 - 1992 period.

ALABAMA

Year	**Dates/ Duration**	**Location/Area**	**Effects**	**Management Decisions**	**Causative Species**	**Toxin/Toxicity/Cell Concentration**
1988	Jul 31	Gulf shores, AL	"Bloom" of filamentous algae heavily infested front beaches; over 2,000,000 dead menhaden found in vicinity of State Park Pier. Could not tie the two occurrences together since water quality had returned to normal following the kill.		*Cladophora* sp.	

ALASKA

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	3/22	Settlers Cove near Ketchikan	PSP, 41-year old female from three steamed clams	Warning about PSP and uncertified areas	*Alexandrium*	61µg/100g (the sample of cooked clams)
1991	Jun 11	Sheep Island; Area not certified (no commercial harvest); harvest for subsistence purposes	4 people had PSP symptom (3 cases)	Samples of butter clams and others to be analyzed for PSP		
1991	Jun 13	Nelson Lagoon	1 person had PSP symptoms from fried cockles	Sample to be analyzed for PSP		
1991	Dec 12	Ketchikan; from Blashke Island (approved oyster and clam harvest area)	1 person reported PSP type symptoms, but unknown cause	Resampled little neck clams were negative for PSP and domoic acid		
1990	Jun 27	Volcano Bay (SW end of Aleutian Peninsula), 28 miles E of village of Cold Bay	One death, 47-year old male; consumed 35-40 butter clams	Two press releases stating risk of harvesting from unapproved areas (recreational beaches)	*Alexandrium*	7,750 psp/100g (butter clams)
1990	Jun 23	Kodiak Island	One individual sought medical assistance after experiencing numbness in face and later in his legs (consumed 20 mussels)	Press release warning about harvesting in uncertified areas	*Alexandrium*	mussel PSP, 1,925 and 2,026 µg/100g
1989	Apr 10	Dutch Harbor, Alaska Peninsula	No effects to 3 adults and 2 children who ate cooked razor clams; a cat ate viscera (guts), was paralyzed and subsequently died	No area on Aleutian Islands is certified commercially for shellfishing		
1988	Jun 15	Alaska Peninsula, 16 miles ENE of Chignik	PSP; 3 people hospitalized (consumption of butter clam, mussels and cockels)	a non-certified area, not an approved commercial shellfishing area		367.2 µg/100g (cockels); 85.0 µg/100g (littleneck clams); 3265.9 µg/100g (mussels)

- Events of only water discoloration and toxicity detection at uncertified areas without any adverse effects were excluded.

CALIFORNIA

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	Apr, Jul, Nov	Sonoma County, Bodega Harbor	PSP in the Washington clam	The Calif. Annual Quarantine was extended to include the Washington clam even beyond the normal quarantine period	*Alexandrium catenella*	120 µg/100g (siphon) and 54 µg/100g (viscera) in Apr; 200 µg/100g (siphon) and 150 µg/100g (viscera) in Jul; 120 µg (siphon) and 100 µg (viscera) in Nov
1991	Aug	Salt Point, Sonoma County	PSP, 11 people affected (3 severely, 1 critically) from sea mussels			2,000 µg/100g
1991	Sept	Santa Cruz	Sick and dying brown pelicans and Brandt's cormorants (domoic acid)		*Nitzschia pseudoseriata (Pseudo-nitzschia australis)*	100-200 ppm (domoic acid in stomach); 50-60 ppm (domoic acid in body parts)
1991	Jul, Aug, Sep, Oct, Dec	Mendocino County	High PSP in wild sea mussels	Annual quarantine was extended indefinitely	*Alexandrium catenella*	PSP, 930 µg/100g (Jul); up to 3300 µg/100 g
1991	Jul, Aug, Oct, Nov, Dec	Sonoma County	High PSP toxin levels in Wild Sea Mussels, Washington Clam, and Basket Cockle	A special quarantine was established to include all bivalve shellfish taken by sport harvesters.	*Alexandrium catenella*	3300µg/100g (wild sea mussels); 100-1,400 µg/100g (Washington Clam); 130 µg/100g (Basket Cockle)
1991	Jan, Feb, Jun, Jul, Aug, Sep	Marin County	High PSP in mussels, oysters, and clams	A special quarantine order to include all bivalve shellfish taken by sport harvesters. The annual quarantine on sport harvested mussels was extended indefinitely; Drakes Bay and the entire Estero were closed to commercial harvesting on Jul 26.	*Alexandrium catenella*	1,900-10,000 µg/100g (mussels); 110-2,500 µg/100g (clams); 1,200-2,200 µg/100g (oysters)

CALIFORNIA (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1990	Mar - Apr; Aug - Nov	Marin County (Drakes Bay Chimney Rock; Drakes Estero Beds #12, #38; Kehoe Beach; Tomales Bay Clam Island; and Lawson's Landing)	High PSP in wild sea mussels, sentinel sea mussels, bay wild mussels, gaper clams, cultured pacific oysters	Emergency quarantine issued for Mar and Apr on sport harvested mussels (persons collecting clams and scallops advised to discard viscera or dark parts and only white meat be prepared for human consumption).	*Alexandrium catenella*	PSP, 160 µg/100g (max) for Mar-Apr; 580 µg/100g (max) for Aug-Nov
1990	Beginning of Jan	San Louis Obispo County (Moonstone Beach Cambria)	PSP in wild sea mussels	Emergency mussel quarantine from Dec 1989 was still in effect. It was lifted on Feb 13, 1990.	*Alexandrium catenella*	PSP, 82 µg/100g
1989	Sep, Oct, Nov	Humboldt County; Affected areas were Humboldt Bay (Mad River, Bird Isl., Indian Isl. Chan., Sand Isl., North Jetty #1 & #2, Comm. Grow Station, Shelter Cove, Trinidad Head, Trinidad Pier, Samoa Bridge (center span)	Extremely elevated concentrations of paralytic toxins in mussels and oysters	Although the annual mussel quarantine was in effect during the bloom, an emergency quarantine was initiated for clams, scallops, native oysters, cockles, and other bivalves. The quarantine was extended beyond the Oct 31 normal deadline to Nov 30, 1989.	*Alexandrium catenella*	paralytic toxins in sentinel (3500 µg) wild (2200µg) bay mussels; wild (4400 µg) sentinel (14000 µg) sea mussels; cultured Pacific oysters (270 µg)
1989	Sep, Oct	Mendocino County; Affected areas were Bruhel Point, Anchor Bay, Caspar Point, South Caspar Headlands, MacKerricher State Park, Pt. Arena Lighthouse.	Paralytic toxins; two non fatal cases of PSP (one adult and one two years old child) reported on 9/10. Both had eaten mussels collected at Anchor Bay.	The annual mussel quarantine was in force, but emergency quarantine was instituted in mid Sept on the taking of clams, cockles, scallops, native oysters, and other bivalves along the north coast.	*Alexandrium catenella*	Paralytic toxins in wild sea mussels reached 6300 µg/100g

CALIFORNIA (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1989	end of Jan, beginning of Feb, Aug, Sep, Oct, Nov, Dec	Sonoma County; Affected areas were Schoolhouse Beach, Bodega Bay South Jetty, Bodega Head, Mussel Point, Salt Point State Park, Duncan Point/Wrights' Beach, Sea Ranch/Black point	Increased paralytic shellfish toxin levels in natural sea mussels and abalone jingle	Quarantine on sport harvesting of mussels during Jan and Feb; the quarantine extended the Oct 31 deadline; public PSP alert via news media	*Alexandrium catenella*	PSP from Aug through Oct reached 5500 µg/100g (wild bay mussel), 1900 µg/100g (wild sea mussel) and 2200 µg/100g (sentinel bay mussel)
1989	Dec (1988); Jan, Feb and an isolated occurrence Mar 4, 1989 Stinson Beach (wild sea mussels)	Marin County; Affected areas were Drakes Estero areas #12 #17, Drakes Bay Chimney Rock Boat Launch, Kehoe Beach, Stinson Beach, Tomales Bay Lawson's Landing	PSP in shellfish (sentinel bay mussels, natural bay mussels, sentinel sea mussels, natural sea mussels, pacific oysters, sentinel Japanese scallops, gapers clams (viscera)	Closure of commercial shellfisheries; emergency quarantine on sport-harvested shellfish from the entire Marin County coastline (quarantine lifted on Mar 20)	*Alexandrium catenella*	
1989	Aug, Sep, early Oct, Dec	Marin County; Affected areas were Drakes Bay Chimney Rock, Drakes Estero Area (#7, #8, #12, #20, #38), Limantour Beach, Tomales Bay (Tomales Point, Lawson's Landing, lease M430-11), Rodeo Beach (high and low rock)	High PSP	Issued public PSP alert via the news media. Since the annual mussel quarantine was still in effect, the importance of complying with it was stressed.	*Alexandrium catenella*	1800 µg/100g (Japanese scallop); 360 µg/100g (cultured Pacific oyster); 1500 µg/100g (cultured bay mussel); 900 µg (wild bay mussel); 1800 µg (sentinel sea mussel); 210 µg (wild sea mussel); 460 µg (unidentified mussel)

CALIFORNIA (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1989	from mid-Aug through Sep, Oct and Nov	San Mateo County; Affected areas were Linda Mar, Moss Beach, Pescadero State Beach, Tunitas Creek	High PSP in wild sea mussels (800 µg/100g)	Annual mussel quarantine was extended beyond the Oct 31 deadline; public PSP alert issued	*Alexandrium catenella*	800 µg/100g (wild sea mussels)
1989	Aug 18, Dec	Monterey County; Affected areas were Pacific Grove Point Pinos, Pfeiffer Beach Big Sur	Slight elevation in PSP in wild sea mussels (110 µg/100g) in Aug and in Dec (130 µg)	Annual mussel quarantine was in effect; emergency quarantine issued in Dec	*Alexandrium catenella*	110 µg/100g in Aug; 130 µg/100g in Dec
1989	late Aug, Sep, Oct, Dec	San Louis Obispo County; Affected areas were Moro Bay, Moonstone Beach, Cambria, North Estero Bay, Estero Bay Cayucos	Elevated PSP in cultured and wild bay mussels, wild sea mussels, and cultured pacific oysters	The annual mussel quarantine (5/1-10/31) was in effect; emergency quarantine was issued in Dec; commercial oyster operations in Moro Bay were shut down	*Alexandrium catenella*	< 1600 µg/100g (sea mussels); < 540 µg/100g (oysters)
1989	mid-Mar, mid-Apr, early May, early Jun, early Jul, mid-Oct, mid-Dec	Santa Barbara County; Affected areas were Civilian Beach, Minute Man Beach, Santa Barbara Channel	Detectable but below alert levels of PSP throughout the year in cultured and wild bay mussels as well as in wild sea mussels; PSP in wild sea mussels exceeded the alert level in Oct and Dec	Mussel quarantine was issued in Dec	*Alexandrium catenella*	
1988	Dec 20	Drakes Estero Area 17 and Drakes Bay, Marin County	PSP toxin in commercial mussel beds	Area closed to commercial harvesting	*Alexandrium catenella*	87 vg/100g (Drakes Estero bay mussels); 290 µg/100g (Drakes Bay sentinel Sea mussels)

- Toxin levels below the alert level (80µg/100g) or high levels within the California annual quarantine period (May 1 - Oct 31) were excluded. These events did not lead to any special management actions.

- Water discoloration events were not entered.

CONNECTICUT

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	May 27 (Mumford Cove); Jul 1 (Palmer Cove)	Town of Groton	High PSP in mussels	shellfish closure (for 5/29 - 7/10)	*Alexandrium* sp.	96.3 µg/100 g, mussels (Mumford Cove); 187.9 µg/100 g, mussels (Palmer Cove)

FLORIDA

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	Sep 1, 1992 - Jan 17, 1993	Pinellas to Lee County	Dead fish (inshore and offshore) from Pinellas to Lee County; respiratory irritation from Pinellas to Lee County; water discoloration from Manatee to Lee County	Shellfish bans: 9/4-1/17 (Longboat Key, Sarasota County); 9/8-1/17 (Lower Tampa Bay, Manatee County); 9/9-1/17 (Lemon Bay, Sarasota County), (Lemon Bay and Gasparilla Sound, Charlotte County), (Pine Island Sound and Matlacha, Lee County); 9/15-1/17 (Boca Ciega Bay, Pinellas County)	*Gymnodinium breve*	from negative to 2,100,000 cells/liter (coastal surface water); from negative to 10,330,000 cells/liter (offshore surface water)
1990	Feb 23 - Mar 22	Pinellas to Lee County	Reports of disoriented and sick sea birds (particularly cormorants); some respiratory irritation on Siesta and Lido beaches (3/3-3/4); reports of dead birds and a few fish off Clearwater (2/9); reports of dead birds and dolphin at Egmont Key (2/9)	Shellfish harvesting ban (2/26-3/23) in Longboat Key (Sarasota County)	*Gymnodinium breve*	up to 233,000 cells/liter (coastal surface water); up to 163,000 cells/liter (offshore, 3-5 miles out)
1990	Oct 18 - Nov 22	Sarasota to Collier County	Dead fish (offshore about 20 miles off Lee County and "massive fish kill" reported by SEAMAP cruise between 10-20 nautical miles offshore from Venice to Sanibel; respiratory irritation and dead fish on Gasparilla Island	Shellfish ban (10/26-11/22) in Lemon Bay and Gasparilla Sound	*Gymnodinium breve*	up to 6,300 cells/liter (coastal surface)
1989	Mar 23 - May 5	Pinellas and Manatee counties	Dead fish (offshore and beach); Gulfport beach closed on 4/9; respiratory and eye irritation	Shellfish bans (3/24 - 5/5) - Pinellas and Manatee counties	*Gymnodinium breve*	< 850,000 cells/liter (coastal surface water); < 12,700 cells/liter (offshore surface); 1,000-14,700 cells/liter (offshore bottom water)

FLORIDA (Continued)

Year	**Dates/ Duration**	**Location/Area**	**Effects**	**Management Decisions**	**Causative Species**	**Toxin/Toxicity/Cell Concentration**
1988	Oct 3 - Dec 20	Pinellas to Collier counties	Dead fish (more than 30 different species noted on some beaches); respiratory irritation; some water discoloration in Oct and Nov.	Shellfish bans: 10/4-12/20 (Pinellas county); 10/3-12/9 (Sarasota county); 10/4-12/9 (Manatee county); 10/11-12/9 (Charlotte county); 10/11-12/20 (Lee county); 10/25-12/20 (Collier county)	*Gymnodinium breve*	ranged from negative to 970,000 cells/liter (coastal surface water); negative to 3,630,000 cells/liter (offshore surface water); negative to 197,000 cells/liter (50' depth water)

- Sep, 1992: Dead fish (from Pinellas to Lee Co.) on beaches (mostly grunts, pinfish and grouper) and 1/4 to 8 miles offshore (catfish, flounder, hogfish, eels, grouper, pinfish, grunts, spadefish, filefish, damsels, angelfish, silver trout, batfish, and other baitfish).

- Nov, 1992: Dead fish - Sarasota and Manatee Co. beaches.

MAINE

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	May - Oct	Kittery to Spruce Head	PSP in shellfish (*Mytilus edulis*, *Mya arenaria*, *Ostrea edulis, Spisula solidissima, Modiolus modiolus, Euspira heros*)	Affected areas closed to the harvest of specific species	*Alexandrium tamarense*	<40-233 µg/100g (*Mytilus*); <40-42 µg g/100g (*Mya*); <40-66µg /100g (*Spisula*); <40 µg (*Ostrea*); <40-52 µg/100g; (*Modiolus*); 96 & 175 µg/100g (*Euspira*)
1992	May - Dec	Vinalhaven to Robbinston (Canadian Border)	PSP in shellfish (*Mytilus edulis, Mya arenaria, Modiolus modiolus, Arctica islandica, Placopecten magellanicus, Euspira heros)*	Affected areas closed to the harvest of specific species	*Alexandrium tamarense*	<40-674 µg /100g (*Mytilus*); <40-669 µg /100g (*Mya*); <40-134 µg /100g (*Modiolus*); 594-1155 µg /100g (*Placopecten*); <40-1242 µg/100g (*Arctica*); <40 & 97µg (*Euspira*)
1991	April - July	Kittery to Spruce Head	PSP in shellfish	Affected areas closed for harvest	*Alexandrium tamarense*	<40-445 µg /100g
1991	July - Aug	Jonesport to Canadian border	PSP in shellfish	Affected areas closed for harvest	*Alexandrium tamarense*	<40-1927 µg /100g
1990	Jun-Nov	Winter Harbor to Canadian Border	PSP in shellfish (*Mytilus edulis, Mya arenaria, Modiolus modiolus, Arctica islandica, Placopecten magellanicus*)	Affected areas closed to the harvest of specific species	*Alexandrium tamarense*	<40-3060 µg /100g (*Mytilus*); <40-1145 µg /100g (*Mya*); <40-1277µg /100g (*Modiolus*); <40-2478 µg 100g (*Placopecten*); <40-587 µg /100g (*Arctica*)
1990	May-Nov	Kittery to Spruce Head	PSP in shellfish (*Mytilus edulis, Mya arenaria, Ostrea edulis, Spisula solidissma, Modiolus modiolus, Lunatia heros*)	Affected areas closed to the harvest of specific species	*Alexandrium tamarense*	<40-1470 µg /100g (*Mytilus*); <40-595 µg/100g (*Mya*); <40-858 µg /100g (*Spisula*); <40-46 µg /100g (*Ostrea*); <40-107 µg /100g (*Modiolus*); 298-1140 µg /100g (*Lunatia*)
1989	May-Aug	Kittery to Spruce Head; Winter Harbor to Robbinston (Canadian Border)	PSP in shellfish (*Mytilus edulis, Mya arenaria, Ostrea edulis, Spisula solidissma, Arctica islandica, Placopecten magellanicus*)	Affected areas closed to the harvest of specific species	*Alexandrium tamarense*	Toxicity ranged from <58 - 7217 µg /100g
1988	May-Jul	Kittery to Pemaquid; Brooklin to Gouldsboro; Trescott to Robbinston	PSP in shellfish	Affected areas closed to the harvest of shellfish	*Alexandrium tamarense*	Toxicity ranged from <58 - 1,400 µg /100g

MAINE (Continued)

Year	**Dates/ Duration**	**Location/Area**	**Effects**	**Management Decisions**	**Causative Species**	**Toxin/Toxicity/Cell Concentration**
1988	Sep	Cobscook Bay and Eastport	Toxicity (domoic acid) in blue mussels (*Mytilus edulis*)	Closure of area to the harvesting of all shellfish	*Pseudo-nitzschia* sp.	Domoic acid concentrations of 5 - 20 ppb.
1988	Sep	Maquoit Bay, Brunswick	Mortalities of marine invertebrates (shellfish and marine worms); coloration of water - brown	Closure of area to the harvesting of all shellfish	*Gymnodinium nagasakiense* (*Gyrodinium aureolum*)	1,800,000 cells/liter; the total cell counts are unlikely to cause anoxia
1988	May 9 to end of July		Toxicity in shellfish	Closure of shellfish beds - *Mya arenaria*, *Mytilis edulis* and other species	*Alexandrium fundyense*	> 80µg/100g; 1,000 - 5,000 cells/liter
1987	Aug, Sep	Cape Porpoise to York, Maine	PSP detected in shellfish	Quarantine	*Alexandrium tamarense*	<58-4215 µg/100g

MASSACHUSETTS

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	throughout the year	Georges Bank	Surf clams (*Spisula solidissima*) continued to retain paralytic shellfish toxins that were accumulated during May and June 1990.	Closure of Georges Bank to harvest of certain molluscan shellfish was continued throughout 1992	*Alexandrium fundyense* and/or *A. tamarense*	100-200 µg/100g (whole animals); 200-500 µg/100g (muscular tissues)
1991	Jun & Jul	Northern Coast	Toxicity in soft-shell clams	Shellfish Closure	*Alexandrium fundyense; A. tamarense*	120µg/100g, PSP
1991	Jun & Jul	Georges Bank	Toxicity in surf clams	Shellfish Closure (scallop fishery was not affected)	*Alexandrium fundyense; A. tamarense*	several hundred µg/100g, PSP
1990	May	Georges Bank	Filter-feeding shellfish (surf clams, ocean quahogs, blue mussels, and scallops) accumulated PSP toxins; 8 fishermen were poisoned (2 seriously and 1 nearly died)	Shellfishing banned; the sea scallop fishery remained open because the adductor muscle remains toxin-free or nearly so	*Alexandrium tamarense*	
1990	mid-May to mid-Jul	North Shore and South Shore of Boston; Southern extent is Cape Cod Canal	Toxicity in shellfish	*Mytilis edulis, Mya arenaria*, and other species closed to shellfishing from late May to mid-Aug; *Spisula solidissima* closed to shellfishing year-round due to retention of the toxins at Georges Bank	*Alexandrium fundyense; A. tamarense*	200-300 µg/100g; 500-2500 cells/liter
1989	mid-May to the end of Jul	North and South Shores of Boston; Southern extent is the east entrance to Cape Cod Canal; Georges Bank in Aug. '89	Toxicity in shellfish (*Mya arenaria, Mytilus edulis*, and others); highest ever recorded shellfish toxicity in MA; toxin detected in surf clams and scallop viscera on Georges Bank; no known human or marine mammal illnesses	Nearshore shellfish bed closures (>80 µg toxin/100g shellfish) for several species; offshore surf clam (Georges Bank) industry closed by NMFS	*Alexandrium fundyense*	200-5,000 cells/liter

MASSACHUSETTS (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1988	May 9 to end of July	North and South Shores of Boston; southern extent is the east entrance to Cape Cod Canal, Nantucket Shoals; isolated outbreaks in Eastham and Orleans on Cape Cod	Toxicity in shellfish; toxin detected in offshore mussels on Nantucket Shoals	Closure of shellfish beds - *Mya arenaria, Mytilis edulis* and other species	*Alexandrium fundyense*	> 80µg/100g; 1,000 - 5,000 cells/liter
1987	Nov, Dec	Massachusetts and Cape Cod Bays	mortality of 15 humpback and 2 minke whales	Public health advisory issued, warning consumers about consuming mackerel, especially the viscera.		Saxitoxin identified in the viscera and liver of mackerel; 40-600 mg/100g of liver or viscera, or about 20 µg/kg fish.

- The important offshore scallop fishery (Georges Bank) has not been affected by the PSP toxicity problem because this fishery utilizes only the adductor muscle, which remains toxin free, or nearly so.

- Georges Bank is an open ocean environment, 100-200 miles from the nearest land (Cape Cod).

NEW HAMPSHIRE

Year	**Dates/ Duration**	**Location/Area**	**Effects**	**Management Decisions**	**Causative Species**	**Toxin/Toxicity/Cell Concentration**
1989	mid-May to the end of July	entire NH coast	Toxicity in shellfish (*Mya arenaria, Mytilus edulis,* and others); no known human or marine mammal illnesses	Nearshore shellfish bed closures (>80µg toxin/100g shellfish) for several species		
1988	May 9 to end of July	entire NH coast	Toxicity in shellfish	Closure of shellfish beds - *Mya arenaria, Mytilis edulis* and other species	*Alexandrium fundyense*	> 80 µg/100g; 1,000 - 5,000 cells/liter

NEW JERSEY

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	7/20 - 7/23; a few lesser blooms of same species reoccurred in the bay during Aug.	Raritan Bay south shore (from Cliffwood Beach to E. Keansburg, especially dense in Keyport Harbor); also extending in lesser intensity from Sandy Hook Bay along NJ coast to about Long Branch, with highest density at Sea Bright.	Kill of marine fauna in vicinity of Cliffwood Beach; roughly 15,000 dead finfish and shellfish were observed over a total stretch of about 2000 yards at Cliffwood Beach; several more dead fish and crabs were seen in Keyport Harbor about the same time (7/21-22)	Increased surveillance by NJDEP and USEPA	*Katodinium rotundatum* (dominant); *Olisthodiscus luteus* and *Euglena/ Eutreptia* spp. (subdominant); *Chroomonas* spp.	< 10^4 cells/ml (*Katodinium rotundatum*); < $5x10^3$ cells/ml (*Olisthodiscus luteus, Euglena/ Eutreptia* spp); other species at around 10^3 /ml
1991	7/20-8/1	Sandy Hook Bay	Brown water; Flocculent deposits	Increase surveillance	Diatoms: *Thalassiosira nordenskioldii, Chaetoceros sociale, Leptocylindrus minimum, Cyclotella* sp.; Chlorophyll *a*	$5x10^4$ cells/ml (Diatoms); > 50 mg/liter (Chlorophyll *a*)
1991	7/25-8/1	Shark River	Water discoloration	Surveillance	*Prorocentrum redfieldi, P. minimum, Gyrodinium* sp., *Euglena* sp., *Katodinium rotundatum, Chroomunas* sp., *Thalassirosira* sp.	$2x10^4$ cells/ml
1991	5/20-6/1	Sandy Hook Bay	Red water	Continued monitoring	*Prorocentrum minimum*	$2.5x10^4$ cells/ml

NEW JERSEY (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1991	early Jun - early Sept	Barnegat Bay	Yellow brown water (summer long); Possible ecological damage in eelgrass mortality	Ongoing surveillance	*Nannochloris atomus*; Chlorophyll *a*	10^6 cells/ml (*Nannochloris atomus*); > 22 mg/l (Chlorophyll *a*)
1990	mid Jun - mid Sept	Barnegat Bay	Yellowish-brown water (summer long); mats of dead eelgrass on shores	On-going surveillance	Chlorophyte *Nannochloris atomys*; Chlorophyll *a*	> 10^6 cells/ml during bloom peaks in late Jul and late Aug; Chlorophyll *a* ranged 15.71-24.26 µg/liter for Jun 12 - Sep 12
1989	mid-Jul to early Sep	Raritan/Sandy Hook Bay (most intense and persistent in the estuary)	Brown water discoloration throughout; resultant brown flocculent material and foam deposits on area shores	Continued surveillance; intensive survey of the estuaries area	(Diatoms) *Skeletonema costatum, Thalassiosira* spp, *Cylindrotheca closterium, Hemiaulus sinensis, Chaetoceros* spp	> 10^5 cells/ml
1989	mid-Jun to early Oct	Barnegat Bay	Brownish water discoloration; large mats of dead eelgrass on shores coincident with brown water; (sport fish catches probably affected)	Continued routine surveillance	(coccoid picoplankton) *Nannochloris atomus*	> 10^6 cells/ml
1988	May 24 - Aug 2	Raritan Bay - Sandy Hook Bay (southern half)	reddish-brown water; fauna kills June 22-28; Aug 2, Sandy Hook Bay south shore. The fauna kill in June included mortalities of finfish, especially northern pipefish, scup, northern sea robin, smallmouth flounder, and summer flounder. Megainvertebrates killed included shore shrimp, sand shrimp, blue crab, and lady crab. The early Aug. kill also involved finfish and shellfish, primarily demersal species (flounder, crabs, etc.).	Increased surveillance	Dominant species (5,000-25,000 cells/ml): *Olisthodiscus luteus, Katodinium rotundatum*, and *Eutreptia lanowii.* Sub dominant species (1,000-5,000 cells/ml): *Procrocentrum minimum*, and *P. triestinum*	Kills attributed to localized hypoxia, contributed by wind and tide. (D.O. levels as low as 2.2 mg/liter)

NEW JERSEY (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1988	May 24 - Jun 8	Raritan Bay and entire coast of New Jersey, from beach to a few miles off	Brown flocculent material, or foam, on much of NJ shore	Increased surveillance	*Ceratulina pelagica; Skeletonema costatum* (in some places)	ranged 1,000-20,000 cells/ml, but usually 1,000-10,000 cells/ml (*Ceratulina pelagica*); 1,000-10,000 cells/ml (*Skeletonema costatum*); Chlorophyll ranged 3-10 µg/l; D.O., at bottom, < 3.0 ppm (Long Beach), and 1.5-4.8 ppm (Seaside Heights)
1988	mid Jul - late Sep	Barnegat Bay	Brownish water discoloration; large mats of dead eel grass on shores	Increased surveillance	*Nannochloris atomus* (dominant); *Aureococcus anophagefferens* (< 7.5%)	100,000-1,000,000 cells/ml (total picoplankton); 12 µg/liter (Chlorophyll North end); 24 µg/liter (Chlorophyll South end)

- Nuisance blooms have occurred only occasionally (usually localized) at Shark River, a relatively small estuary. Occasional red tides in the adjacent coastal waters have had greater adverse impact (i.e., complaints of respiratory irritation by bathers) -- occurrences were in 1968,1972, and 1980-82.

- Water discoloration incidents were excluded.

NEW YORK

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	Jan-Dec with peak concentrations during Jul and Aug	Great South Bay; the bloom was present throughout the bay with highest concentrations occurring in the central bay area between Bayshore and Patchogue	Aesthetic (brown water); reduced transparency possibly affecting growth of rooted vegetation in deeper areas; appears to affect growth and reproduction (larval survival) of shellfish species (primarily hard clam, *Mercenaria mercenaria*, in Great South Bay)	increased frequency of monitoring activities	*Aureococcus anophagefferens*	ranged from >10^3 to >10^6 cells/ml; 5.4-10.7 mg/liter (dissolved oxygen)
1992	Apr - Dec with peak concentrations during Jun and Jul	Moriches and Shinnecock Bays; bloom was concentrated in eastern Moriches Bay, western Shinnecock Bay and their interconnecting embayment, Quantuck Bay	Aesthetic (brown water); reduced transparency possibly affecting growth of rooted vegetation in deeper areas; appears to affect growth and reproduction (larval survival) of shellfish species (primarily hard clam, *Mercenaria mercenaria*, in Great South Bay)	increased frequency of monitoring activities	*Aureococcus anophagefferens*	7.2-11.7 mg/liter (dissolved oxygen)
1992	May - Oct with peak concentrations occurring during Jun and Jul	West Neck Bay and Coecles Harbor, Shelter Island on the eastern end of the Peconic Bay System	Aesthetic (brown water); reduced transparency possibly affecting growth of rooted vegetation in deeper areas; appears to affect growth and reproduction (larval survival) of shellfish species (primarily hard clam, *Mercenaria mercenaria*, in Great South Bay)	Continue weekly monitoring program; increase parameters investigated and funding of research activities	*Aureococcus anophagefferens*	up to 10^6 cells/ml (West Neck Bay); up to 8.5×10^5 cells/ml (Coecles Harbor); 6.5-8.4 mg/l (dissolved oxygen)
1991	May-Sept	Peconic Bay system	Deleterious effects on various shellfish species; water discoloration; reduced transparency	Continue weekly monitoring	*Aureococcus anophagefferens*	10^6 cells/ml
1990	Apr-Jul; Sep-Oct	West Neck Bay, Shelter Island	Water discoloration and reduced transparency	Continue weekly monitoring	*Aureococcus anophagefferens*	5.6×10^5 cells/ml (Jul); 1.8×10^4 cells/ml (Oct)

NEW YORK (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1990	Jun; lasting for about 1 week	Nassau County north shore harbors	Extensive green discolored water; generated numerous complaints; some oyster post-set deaths noted by local commercial oyster company	Monitor; press release	*Eutreptiella* sp.	up to 17 mill. cells/liter
1990	late Jun to mid Jul; picked up again by early Sep	Nassau County north shore harbors; especially Cold Spring Harbor and Hempstead Harbor, Manhasset Bay	Numerous complaints of discolored water and "sewage/sludge" Jubilee-type fish kill affecting primarily baby flounder in Cold Spring harbor - Jul 12th; dead *Mytilus edulis* and *Cancer irroratus* in Manhasset Bay - Jul 10-13th	Sample; press release	*Prorocentrum triestinum;* *Eutreptiella* sp.; *Skeletonema* *Rhiosolenia fragilissima;* *Chaetoceros perpusillus;* *Sinophysis acuminata*	up to 50 mill. cells/liter
1990	Jul - Dec	Moriches and Shinnecock Bays; the bloom was mainly concentrated in eastern Moriches Bay and western Shinnecock Bay	Primarily aesthetic effects; water discoloration and reduced transparency	Increase monitoring frequency	*Aureococcus anophagefferens*	10^4 to 9.6×10^5 cells/ml at eastern Moriches Bay and western Shinnecock Bay; 10^3 to 10^5 cells/ml at other areas
1989	Aug 1 (initial observation)	Nassau County, Near shore Long Island Sound and within the North Shore harbors (especially Hempstead Harbor)	Distinct brown water discoloration; one possible illness episode later in fall (2 persons with DSP like symptoms) from local clams	Increased surveillance and sampling toxicity with "UBE" test	*Dinophysis acuminata*	700,000 cells/l (highest count); UBE test results, > .5 MU (2 stations)
1988	mid June	Great South Bay and Peconic Bay System, Long Island	Isolated blooms peaked in mid June, then dwindled to undetected levels by end of summer	Suffolk County monitoring program was carried out	*Aureococcus anophagefferens*	< 500,000/ml max cell number in Great South Bay; up to 1,000,000/ml in Peconic system
1988	May 26 - Aug 18	W. Sayville, NY; Great So. Bay, Long Island	Growth suppression in *M. mercenaria*; delay of spawning in *M. mercenaria* until count/ml decreased to much lower levels (< 350,000/ml)	Raw water upwelling systems moved to L.I. Sound to avoid *Aureococcus* ("Wait it out")	*Aureococcus anophagefferens*	

NEW YORK (Continued)

Year	**Dates/ Duration**	**Location/Area**	**Effects**	**Management Decisions**	**Causative Species**	**Toxin/Toxicity/Cell Concentration**
1987	Jul '87 - Feb '88	Peconic Bay and Great South Bay, Long Island	Mortality of juvenile and larval scallops; water coloration - brown; eelgrass mortality	Re-seeding of juvenile scallops attempted; unsuccessful due to mortality	*Aureococcus anophagefferens*	< 1,000,000 cells/ml (*Aureococcus anophagefferens*); < 25-30 µg/liter (chlorophyll); normal oxygen condition

- Short-lived water discoloration events were not entered.
- An extremely dense and widespread bloom in Nassau County north shore harbors in mid-July, 1987.
- Low level detections of PSP were not entered.

NORTH CAROLINA

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	throughout late summer and winter (in Core Sound)	Neuse and Pamlico River/Estuary & Core Sound; Coastal waters off Willmington, NC	small fish kills / shellfish kills (localized)	none	"Phantom" dinoflagellate	
1991	5/15, 8/4, 9/10, 10/7-20, 12/15	Pamlico River, Taylor Creek, Neuse River	Massive kills of finfish & shellfish; separate fisheries and public health effects	Sampling protocol to detect and verify presence of the toxic dinoflagellate	new species within genus *Alexandrium*	
1987	Nov '87 - Feb '88	Continental shelf of NC south and west of Cape Lookout, including sounds and inlets inside the Outer Banks and southern Barrier Islands	Neurotoxic shellfish poisoning (NSP), 48 illnesses; respiratory irritation in humans; fish and scallop mortalities (more than 50%); water coloration - visible	Shellfish quarantine for waters to south of Cape Hatteras	*Gymnodinium breve*	< 20,000,000 cells/liter

- Burkholder and Noga have associated the new species (now known as *Pfiesteria piscicida*) with approximately 25% of the fish kills which have occurred in the Pamlico and Neuse estuaries. About 25% of fish kills in these estuaries have been associated with "sudden death" of many fish species and shellfish which exhibited neurotoxic symptoms.

- An incident of 4,700 cells/liter *Ptychodiscus brevis* (below the shellfish bed closure level of 5,000 cells/liter) was not entered.

[ECONOMIC IMPACT INFORMATION]

- For the Nov '87 - Feb '88 red tide, the economic losses to the coastal community were conservatively estimated at $25 million (Tester *et al.* 1988).

OREGON

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	about 2-3 Oct	off Florence (a distance of approximately 36 miles): 44°38' N, 125°58' W to 44°27' N, 125°10' W	Dead fish (mackerel) covering a large area; no birds were eating the dead fish and there were no other species of dead fish.		Not confirmed, possibly *Alexandrium catenella*	Dead mackerel (Oct): 187-201 µg/100g (viscera), <38-41 µg/100g (meat). Live mackerel (Nov): 97-116 µg/70g (viscera), <37 µg/100g (meat). Live rockfish (Nov): <30 µg/80g (viscera), <36 µg/100g (meat)
1992	late Jul - early Aug with mussels; peaked in late Sep - early Oct with mussels	from Reedsport to the Columbia River (ca. 43.7 - 46.7 degrees N.)	Closure of razor clam commercial and recreational harvest caused severe economic problems for at least 2 businesses; mussel harvest also closed, but most is done south of the closure area. One report of PSP in Dungeness crab viscera causing a health warning to people who eat crab viscera, additional testing to ensure safe crab for export. One report of dead mackerel containing PSP off the coast.	Harvest closure for all shellfish north of Reedsport as of 12 Aug; oysters and bay clams lot sampled in Sep & Oct; shellfish other than razor clams and mussels released from closure in early Nov; razor clams and mussels remained closed through the end of 1992	thought to be *Alexandrium catenella*	PSP, 88 µg/100g in mussels (late Jul - early Aug); (<4367 µg/100g), oysters (80 µg/100g) and little neck clams (225 µg/100g) affected; razor clams (210 µg/100g) affected in Nov.
1991	Oct - Nov		28 human illnesses reported in WA & OR (mild); razor clams and Dungeness crabs became intoxicated with domoic acid	Closure of commercial and recreational harvest of razor clams on WA and OR beaches; closed commercial fishery for Dungeness crabs from northern Cal. to northern Wash. for a month	*Pseudo-nitzschia australis*	Razor clams were still toxic in mid March '92 with domoic acid levels of 30-60 ppm (regulatory closure level is 20 ppm)
1989	Oct, Nov	Oregon coast	Elevated PSP levels in Oct and Nov; exceeding 80 µg/100g in Nov	Closure of portions of the central Oregon coast from 15-28 Nov for shellfishing	*Alexandrium catenella*	PSP; 89.4 µg/100g (11/14); 113 µg/100g (11/19)

- In 1991, Oregon PSP alert began in 9/25/91 on the general beaches in mussels, peaking at 150 µg/100g and declining to < 50 µg/100g by 10/30/91.

TEXAS

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1990	May 1990 - Apr. 1994 (bloom continued for >7 years)	in ship channel running off Laguna Madre near Brownsville	Fish kills and limited reports of aerosol (respiratory irritation)	Shellfish harvesting bans south of Port Mansfield (Nov 1990 - Mar 1, 1991, still continuing at the time of this report)	*Gymnodinium breve*	up to 300,000 cells/liter

- *G. breve* bloom extended along much of Texas coast in 1986.

WASHINGTON

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1992	late Sep - early Oct	Pacific coast of Washington State and coastal estuaries of Willapa Bay and Grays Harbor	Shellfish toxicity (PSP) - highest levels measured in razor clams in the surf zone. Lower levels in commercial oysters and clams within coastal estuaries	Postponement of recreational razor clam fishery opening scheduled for Oct 9 until Nov 13, 1992. Closure of commercial oyster beds in Willapa Bay and Grays Harbor. Minor product recall.	*Alexandrium catenella*	Razor clams: 720 µg/100g (meat), 3500 µg/100g (viscera). 197 µg/100g in Pacific oysters in Grays Harbor estuary.
1992	29 Apr	Glen Ayr Marina, Hoodsport, southern Hood Canal	Morning: 90g fish (Deschutes stock fall chinook salmon) off feed. Afternoon: fish rapidly dying; became pale in color, gills were bright orange with tips of gill filaments bent; kidneys were soft and bloody. There were no other pathogens present.	Fish were released from net pens; probably few survived.	Unknown, but a 28-30 µm diameter, pigmented, *Gymnodinium*-like dinoflagellate was present. Also, *Pseudo-nitzschia pungens* f. *pungens*.	
1991	Oct - Dec		28 human illnesses reported in WA & OR (mild); razor clams and Dungeness crabs became intoxicated with domoic acid	Closure of commercial and recreational harvest of razor clams on WA and OR beaches; Closed commercial fishery for Dungeness crabs from northern Cal. to northern Wash. for a month	*Pseudo-nitzschia australis*	Razor clams were still toxic in mid March '92 with domoic acid levels of 30-60 ppm (regulatory closure level is 20 ppm)
1990	1-14 Jul	Central Puget Sound, Samish and Bellingham bays, Port Angeles harbor, Port Townsend Bay, northern Hood Canal	Killed Atlantic salmon in net pens (central Puget Sound); large fish (brood stock) were affected first; also killed brood stock of White River spring chinook salmon in net pens	Fish growers harvested fish; two growers towed their pens to clear water	*Heterosigma akashiwo*	50,000 - 4,000,000 cells/liter (at pen sites); > 12,000,000 cells/liter detected in Port Angeles harbor

WASHINGTON (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1990	Sep 19-24	Liberty Bay	High toxin in shellfish	Liberty Bay closed to all commercial and sport harvesting of shellfish; recall of commercially harvested oysters from 17 states (no illnesses reported)	*Alexandrium catenellum*	toxin levels were 226-358 µg/100g
1990	mid to end of Aug	Pacific coast of Washington, Vancouver Island, (B.C.), throughout San Juan Islands (WA)	High concentration of algal cells; no harmful effects (fish growers worried about effect on net-pen fish)		*Gonyaulax spinifera*	1.5-4.5 mill cells/liter in patches; formed cysts
1990	Oct	Dabob Bay	High cell concentration; no effects only because fish growers in the area did not have fish in the water		*Chaetoceros concavicornis*	40,000 - 74,000 cells/liter, and up to 10 mill cells/liter
1989	Nov 18 to the reported date (Jan 10, 1990); The toxic bloom was still present at the time of reporting.	American Lake, Pierce County	As of Jan 10, 1990, 5 dead cats, 1 ill cat, 1 dead dog, 5 ill dogs and 3 dead waterfowl were suspected to have been due to the algae (first reported animal illness); a few necropsys have been performed, but were inconclusive	Media notified; fact sheets distributed to residents around the lake; public access sites posted with warning signs	*Anabaena flos-aquae*	Anatoxin-A
1989	Sep 5-9 (peak fish mortality in Cypress Island); Sep 8-10 (Port Angeles)	Cypress Island and Port Angeles (northern Puget Sound)	Massive kills of Atlantic salmon in net pens; also chinook salmon and rainbow trout; most smaller fish survived. Larger fish died first, especially brood stock.	Rapid harvest of dead and moribund fish; stopped feeding and other activity around the pens; Port Angeles had more warning and placed tarps around the pens to cut down water circulation and had little loss.	*Heterosigma akashiwo* (Hada) Hada	Cells generally concentrated in upper 2 m of water.

WASHINGTON (Continued)

Year	Dates/ Duration	Location/Area	Effects	Management Decisions	Causative Species	Toxin/Toxicity/Cell Concentration
1989	Aug 1	Flounder Bay, Fidalgo Island	High PSP detected	Commercial shellfish product recalled; of 150 pounds, all but 7 pounds was recovered and destroyed; closure for commercial shellfishing	*Alexandrium catenella*	804 µg/100g (Washington sample); 470 µg/100g (California, product receiver state, sample)
1988	mid Sep	Carr Inlet, Puget Sound	5 confirmed illnesses from consumption of commercial shucked oysters; no recreational illnesses reported	Immediate closure of recreational and commercial harvesting, reopened Oct 6; recalled 2 weeks production - Minterbrook Oyster Co.	*Alexandrium catenella*	up to 2,400 µg/100g (PSP)
1987	various phyto-plankton blooms	Cypress Island	mortality of at least 250,000 Atlantic and Pacific salmon		*Chaetoceros concavicornis*	

[ECONOMIC IMPACT INFORMATION]

- For the 1992 (Sept -Oct) PSP event, the commercial shellfish industry estimated the loss of "$1million" due to recall and closures.
- For the 1990 (July 1-14) fish kill, the dead fish were estimated to be worth $4-5 million (Horner *et al.* 1991).
- For the 1989 (Sept 5-9) fish kill, the losses to three farms and four separate net-pen systems: 2,000,000 lbs. or about 95% of the total crop.
- For the 1987 fish kill, the losses were over $0.5 million (Rensel *et al.* 1990).

APPENDIX B

List of Local Experts Contacted by Letters

GENERAL

Sandra E. Shumway
Natural Science Division
Southampton College, LIU
Southampton, NY 11968
Sshumway@southampton.liunet.edu

ALASKA

Ronald K. Dearborn
Alaska Sea Grant College Program
University of Alaska
138 Irving II
Fairbanks, AK 99775-5040
Fnrk@uaf.edu

Michael J. Ostasz
Shellfish Program Coordinator
Department of Environmental Conservation
3601 C Street, Suite 1324
Anchorage, AK 99503
Mostasz@envircon.state.ak.us

Craig Wiese
Sea Grant Program
University of Alaska, Fairbanks
2221 E. Northern Lights Blvd, #110
Anchorage, AK 99508

CALIFORNIA

James A. Fawcett
University of Southern California Sea Grant
Hancock Institute for Marine Studies
University Park
Los Angeles, CA 90089-1231

James J. Sullivan
California Sea Grant College Program
Univ. of California - San Diego A-032
La Jolla, CA 92093

Kenneth Hansgen
Department of Health Services, EHSS
Sacramento Office
714 P Street, Rm. 616
Sacramento, CA 95814

Richard E. Danielson
Department of Health Services
Sanitation and Radiation Laboratory
2151 Berkeley Way
Berkeley, CA 94704

Greg Langlois
Department of Health Services
2151 Berkeley Way, Rm. 118
Berkeley, CA 94704

Sue Yoder
University of Southern California
University Park
Los Angeles, CA 90089-1231

CONNECTICUT

Edward C. Monahan
Connecticut Sea Grant College Program
University of Connecticut
Avery Point
Groton, CT 06340
Sgoadm01@unconnvm.unconn.edu

Malcolm Shute
Connecticut Department of Agriculture
Aquaculture Division
P.O. Box 97
Rogers Avenue
Millford, CT 06460
Dept.agric@snet.net
Subject Line: Attention Malcolm Shute

James Citak
Aquaculture Division
Department of Agriculture
State of Connecticut
P.O. Box 97
Milford, CT 06460
Dept.agric@snet.net
Subject Line: Attention James Citak

John Volk, Director
Department of Agriculture
State of Connecticut
P.O. Box 97
Milford, CT 06460
Dept.agric@snet.net
Subject Line: Attention John Volk

DELAWARE

Carolyn Thoroughgood
Delaware Sea Grant College Program
Graduate College of Marine Studies
Robinson Hall
Newark, DE 19716
C.Thoroughgood@mvs.udel.edu

FLORIDA

James C. Cato
Florida Sea Grant College Program
Building 803
University of Florida
Gainesville, FL 32611
Jcc@gnv.ifas.ufl.edu

Beverly Roberts
Marine Research Laboratory
Florida Dept. of Natural Resources
100 Eighth Ave., SE
St. Petersburg, FL 33701-5095
Bev.Roberts@dep.state.fl.us

GEORGIA

Mac Rawson
Georgia Sea Grant College Program
University of Georgia
Ecology Building
Athens, GA 30602
Mrawson@arches.uga.edu

Brad Williams
Shellfish Program Leader
Georgia Department of Natural Resources
1 Conservation Way
Brunswick, GA 31523-8600

HAWAII

Jack R. Davidson
Hawaii Sea Grant College Program
University of Hawaii
1000 Pope Road, Rm. 223
Honolulu, HI 96822

Yoshitsugi Hokama
Department of Pathology
Room T-512
University of Hawaii
1960 East-West Road
Honolulu, HI 96822

LOUISIANA

Jack R. Van Lopik
Louisiana Sea Grant College Program
128 Wetland Resources
Louisiana State University
Baton Rouge, LA 70803-7507

Ronald Becker
Louisiana Sea Grant College Program
Louisiana State University
Baton Rouge, LA 70803-7507
Rbecker@lsu.edu

MAINE

Robert E. Wall
Maine/N.H. Sea Grant College Program
University of Maine
14 Coburn Hall
Orono, ME 04469-0114

Laurie Bean
Dept. of Marine Resources
Bureau of Marine Science
West Boothbay Harbor, ME 04575
Laurie.Bean@state.me.us

Sally Sherman-Caswell
Department of Marine Resources
McKown Point Rd.
West Boothbay Harbor, ME 04575
Sally.Sherman@state.me.us

John W. Hurst, Chairman
Fisheries and Health Science Division
Department of Marine Resources
West Boothbay Harbor, ME 04575
John.Hurst@state.me.us

Robert Lewis
Dept. of Marine Resources
State House Station 21
Augusta, ME 04333-0021

MARYLAND

Chirstopher F. D'Elia
Maryland Sea Grant College Program
University of Maryland
0112 Skinner Hall
College Park, MD 20742
Delia@cbl.umces.edu

MASSACHUSETTS

Chryssostomos Chryssostomidis
MIT Sea Grant College Program
Massachusetts Institute of Technology
Bldg. E38, Rm. 330
77 Massachusetts Ave.
Cambridge, MA 02139
Chrys@deslab.mit.edu

E. Eric Adams
Department of Civil Engineering
Bldg. 48-325
MIT
Cambridge, MA 02139
Eeadams@mit.edu

Michael Hickey
Massachusetts Division of Marine Fisheries
18 Route 6A
Sandwich, MA 02563

Paul DiPietro
MDC
6th Floor
20 Somerset Street
Boston, MA 02108

Alan White
Department of Marine Safety and Environmental Protection
Massachusetts Maritime Academy
101 Academy Drive
Buzzards Bay, MA 02532
Awhite@mma.mass.edu

Dave Whittaker
Division of Marine Fisheries
18 Route 6A
Sandwich, MA 02563
David.Whittaker@state.ma.us

MISSISSIPPI

James I. Jones
Mississippi/Alabama Sea Grant Consortium
P.O. Box 7000
703 East Beach Drive
Ocean Springs, MS 39564-7000

NEW HAMPSHIRE

Brian Doyle
New Hampshire/Maine Sea Grant College Prog.
Marine Program Building
University of New Hampshire
Durham, NH 03824
Brian.doyle@unh.edu

John Nelson
NH Fish & Game / Region 3
225 Main Street
Durham, NH 03824-4732

Paul Raiche, Supervisor
Dept. of Health and Human Services
Division of Public Health Services
6 Hazen Drive
Concord, NH 03301-6527

NEW JERSEY

William G. Gordon
N.J. Marine Sciences Consortium
Sea Grant Program
Building No. 2
Fort Hancock, NJ 07732

Paul Olsen
NJ Dept. of Environmental Protection
Division of Water Resources
Geological Survey CN 029
Trenton, NJ 08625

NEW YORK

Anne McElroy
New York Sea Grant Institute
Dutchess Hall, Rm. 147
State Univ. of New York - Stony Brook
Stony Brook, NY 11794-5001
Amcelroy@notes.cc.sunysb.edu

Robert Nuzzi
Suffolk County Dept. of Health Services
Riverhead County Center
Riverhead, NY 11901

Anita Freudenthal
Nassau County Dept. of Health
240 Old Country Rd.
Mineola, NY 11501

NORTH CAROLINA

B. J. Copeland
Univ. of North Carolina Sea Grant College
North Carolina State University
Box 8605
Raleigh, NC 27695-8605
Bjcopela@unity.ncsu.edu

JoAnn Burkholder
Department of Botany
Box 7612
North Carolina State University
Raleigh, NC 27695
Joann_burkholder@ncsu.edu

Pat Tester
NOAA/NOS
Beaufort Laboratory
Beaufort, NC 28516-9722
Pat.Tester@NOAA.gov

Mike Street
Dept. of Environmental Health and Natural Resources
Division of Marine Fisheries
Morehead City, NC 28557-0769
Mike.Street@ncmail.net

Bob Curry
North Carolina Wildlife Resources Commission
512 N. Salisbury Str.
Raleigh, NC 27604-1188

Karen M. Lynch
Environmental Sciences Branch
DEHNR
State of North Carolina
4401 Reedy Creek Road
Raleigh, NC 27607

OREGON

Robert Malouf
Oregon Sea Grant College Program
Administrative Services Building - A320
Oregon State University
Covallis, OR 07331-2131
Robert.Malouf@orst.edu

Debora Cannon
Department of Agriculture
Food & Dairy Division
635 Capitol Street NE
Salem, OR 97310

John Johnson
Dept. of Fish and Wildlife Service
2040 SE Marine Science Drive
Newport, Oregon 97365

PUERTO RICO

Manuel Hernandez-Avila
Puerto Rico Sea Grant College Program
University of Puerto Rico
Department of Marine Sciences
RUM-UPR, P.O. Box 5000
Mayaquez, PR 00708

RHODE ISLAND

Scott Nixon
Rhode Island Sea Grant College Prog.
University of Rhode Island
Marine Resources Building
Narragansett, RI 02882
Snixon@gsosun1.uri.edu

Joe Migliore
Senior Environmental Scientist
Rhode Island Dept. of Environmental Management
Division of Water Resources
291 Promenade Street
Providence, RI 02908-5767
Jmiglior@dem.state.ri.us

SOUTH CAROLINA

Margaret Davidson
South Carolina Sea Grant Consortium
287 Meeting St.
Charleston, SC 29401

Rick Devoe
South Carolina Sea Grant consortium
287 Meeting Str.
Charleston, SC 29401
Devoemr@musc.edu

TEXAS

Thomas J. Bright
Texas Sea Grant College Program
1716 Briarcrest Drive
Suite 702
Bryan, TX 77802

Richard Thompson, Director
Division of Shellfish Sanitation Control
Texas Department of Health
1100 West 49th Street
Austin, TX 78756

Eleanor Cox
Department of Biology
Texas A&M University
College Station, TX 77843
e-cox@tamu.edu

Terry E. Whitledge
Marine Science Institute
University of Texas - Austin
P.O. Box 1267
Port Aransas, TX 78373-1267

Kirk Wiles
Texas Dept. of Health
1100 W. 49th Street
Austin, TX 78753

Ed Buskey
Marine Science Institute
0University of Texas, Austin
Port Aransas, TX 78373
Buskey@utmsi.utexas.edu

VIRGINIA

William L. Rickards
Virginia Sea Grant College Program
University of Virginia
Madison House - 170 Rugby Road
Charlottesville, VA 22903
Rickards@virginia.edu

WASHINGTON

Louis S. Echols
Washington Sea Grant College Program
University of Washington
3716 Brooklyn Ave., N.E.
Seattle, WA 98105-6716
Echols@u.washington.edu

Mary McCallum
Washington State Dept. of Health
Shellfish Office, Mail Stop LD-11
Olympia, WA 98504

Jack Rensel
Rensel Associates
2412 North 77th Street
Seattle, WA 98103
Jackrensel@email.msn.com

Doug Simons
Dept. of Fish and Wildlife
48 Devonshire Rd.
Montesano, WA 98563
Simondds@dfw.wagov

CANADA

Ewen Todd
Health Protection Branch
Health and Welfare Canada
Sir Frederick G. Banting Research Centre
Tunney's Pasture, Ottawa
Ontario K1A 0L2 Canada