30 The Economic Effects of Harmful Algal Blooms

P. Hoagland and S. Scatasta

30.1 Introduction

In this chapter, we focus on how economists approach the problem of measuring the adverse effects of harmful algal blooms (HABs), as one type of natural hazard occurring in the coastal ocean. We start by drawing a distinction between scientific and economic approaches to assessments of the effects of HABs. We note that economists concern themselves with developing measures of changes in value (especially economic losses) as a consequence of HABs. This interest is motivated primarily by society's need to design responses to HABs that could mitigate economic losses at an appropriate scale. In other words, societal responses to HABs should be cost-minimizing, when all the relevant costs are considered. In this chapter, we focus on the costs of the adverse consequences of HABs, not on the costs of societal responses.

We address measures that are used to estimate changes in economic value, noting that some commonly used measures of "economic effects" are not necessarily good measures of changes in economic value. We provide some examples of measures from both published and unpublished studies in the European Union (EU) and in the United States (US). We compare estimates of economic effects from both jurisdictions, finding such estimates roughly comparable for effects in public health, commercial fisheries, and monitoring and management. The economic effects of HABs on tourism apparently are much larger in the EU, where these effects are the consequence of noxious but nontoxic blooms. We conclude with a call for increased attention to the development of estimates of changes in economic value from HABs, so that society's resources can be directed to respond to these hazards more effectively.

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30.2 Scientific Concerns

Marine scientists measure the effects of natural hazards, such as HABs, in different ways than do economists. Many scientists are concerned primarily with changes in the natural environment or with changes in the behavior of specific organisms or the characteristics of ecosystems. An important scientific concern is to understand the causes and effects of the spatial and temporal distributions of the algal species of which a harmful algal bloom (HAB) is composed.

The concerns of marine scientists are illustrated by a recent widespread bloom of the toxic dinoflagellate *Alexandrium fundyense* in the Gulf of Maine, a large body of water off the coast of New England. News reports have tracked oceanographers as they sample the ocean to determine the number of algal cells per liter of water. The scientists feed their data on algal density and distribution into models of bloom formation, spreading, and eventual decay. The models are designed to describe bloom dynamics by linking environmental factors such as precipitation, riverine nutrient fluxes, wind and current velocities, and insolation with the physical characteristics of blooms. If proven reliable, a model of bloom dynamics might enable future predictions of the timing, scale, and scope of HABs in the Gulf. These predictions could prove useful for shellfishermen, aquaculturists, and other users of the marine environment.

30.3 Economic Concerns

In contrast to scientists, economists focus their attention on changes in the patterns of human activities or resource uses that can result from a natural hazard (this interest in understanding the effects on humans exists regardless of whether the hazard is naturally occurring or is the consequence of anthropogenic activities. Where human activities lead to or exacerbate the effects of HABs, the potential set of responses that could be invoked to mitigate the effects may be different than those used to respond to HABs that occur naturally). These changes, in turn, may affect the value that humans realize from, or assign to coastal and marine activities and uses. For example, if shellfishermen are provided with information about the potential onset of a HAB event, will they respond in a way that mitigates the economic losses that they may incur?

For example, when a HAB in the US or the EU results in sampled saxitoxin concentrations in excess of 80 μg per 100 mg of molluscan tissue, then commercial and recreational fishermen and growers are precluded by law from harvesting and selling shellfish. Cordoned-off thereby from the market, these fishermen and growers will experience economic losses as a consequence of the bloom, while consumers will experience an economic gain from avoiding shellfish poisoning. Economists seek to measure the scale of gains and losses like these (also referred to by economists and others as economic "benefits" and "costs" or "damages") and to express them in monetary terms.

Marine scientists also may share a concern about appropriate societal responses to HAB events. Many of these concerns appear in a recent document outlining the rationale for an expanded national program on HAB research in the US (Ramsdell et al. 2005). Because of their intimate understanding of the physical and biological mechanisms of blooms, scientists may be more likely than economists to come up with ideas for physically controlling either the bloom itself or the factors that lead to bloom formation.

30.4 Why Measure Economic Losses?

Why do economists care about measuring economic losses from HABs? The primary reason is that the scale of the economic losses can tell us something about the appropriate scale of actions taken to prevent or mitigate the losses. At the very least, if one can take some action that removes the threat of a harmful bloom, then more resources (measured in financial terms) should not be spent taking the action than the actual economic losses associated with the bloom itself.

Where the set of feasible actions that can be taken to mitigate a bloom are not of the all-or-none type, economists would argue for more precision in optimizing a societal response to HABs. Applying a body of theory known as "welfare economics," economists would argue for implementing a single action or combination of actions at levels that minimize the total cost of a bloom. The total cost can be decomposed into two main parts: (1) the economic losses caused by a bloom and (2) the costs of mitigating economic losses. Figure 30.1 depicts a stylized economic approach. In the figure, economic losses decline with larger levels of mitigation. At the same time, as more mitigation is undertaken, the unit costs of mitigation increase. When these cost curves intersect, as depicted in Fig. 30.1, a standard result from the economic theory of pollution control is that the cost-minimizing level of mitigation may be such that society might need to bear a non-zero level of loss from a bloom. In other words, part or all of the response to many HAB events is just to put up with them. Depending upon the type of bloom and the affected human uses, a variety of actions may be feasible, from increasing the frequency of environmental monitoring to closing a shellfish bed to relaying shellfish into unaffected areas (or pounds) to spraying clay over the water surface. Scientific research about bloom formation and dynamics and about potential ecological effects is a crucial activity that identifies and complements mitigation actions.

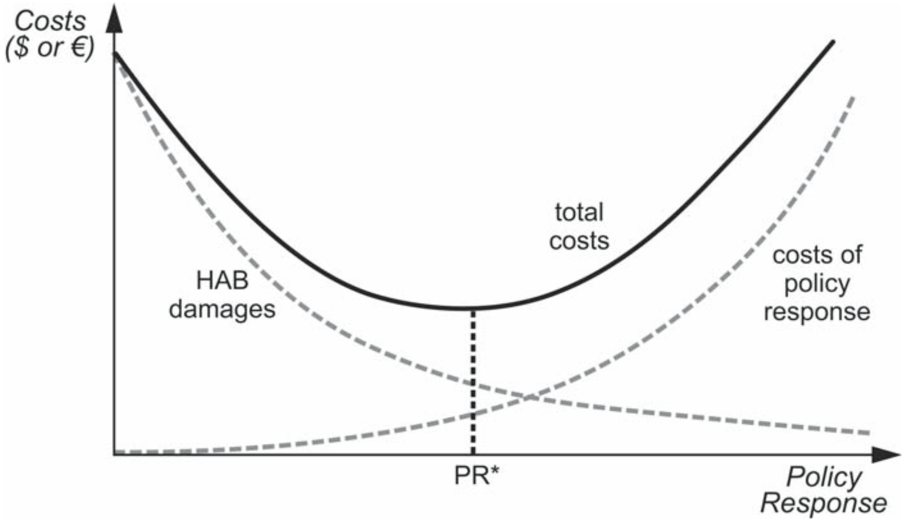

Fig 30.1. Determining the most efficient action or set of actions to respond to a HAB event requires estimates of both the adverse economic effects ("*HAB damages*") and the costs associated with actions taken to mitigate the adverse effects. The optimal response (*PR**) is at that level where the sum of damages and response costs (*total costs*) is minimized

30.5 Economic Losses

The concept of "value" has many definitions in many contexts. In economics, however, value is defined strictly as a surplus. Van den Bergh et al. (2002) present an excellent overview of the economic methodology for measuring surplus changes in the case of HABs introduced through ballast water discharges. There are two kinds of economic surplus. The first kind, known as consumer surplus, is what the purchasers of a good or service are willing to pay, above what they actually have to pay in a market setting. The second kind of surplus, known as a producer surplus, is what firms or other suppliers of a good or service earn in excess of their costs of production.

In a market, the total surplus is the sum of consumer and producer surpluses. In order to estimate the effects of a natural hazard such as a HAB event, economists seek to measure any changes (typically reductions) in total surplus as a consequence of the event. The concepts of consumer and producer surplus are illustrated in Fig. 30.2. In the figure, consumer surplus is the area underneath the demand curve and above the equilibrium price (area P_0bg without HABs). The impact of HABs on consumer surplus is given by the area P_1abP_0. Producer surplus is given by the area above the supply curve and below the equilibrium price (area P_0bd without HABs). The impact of HABs

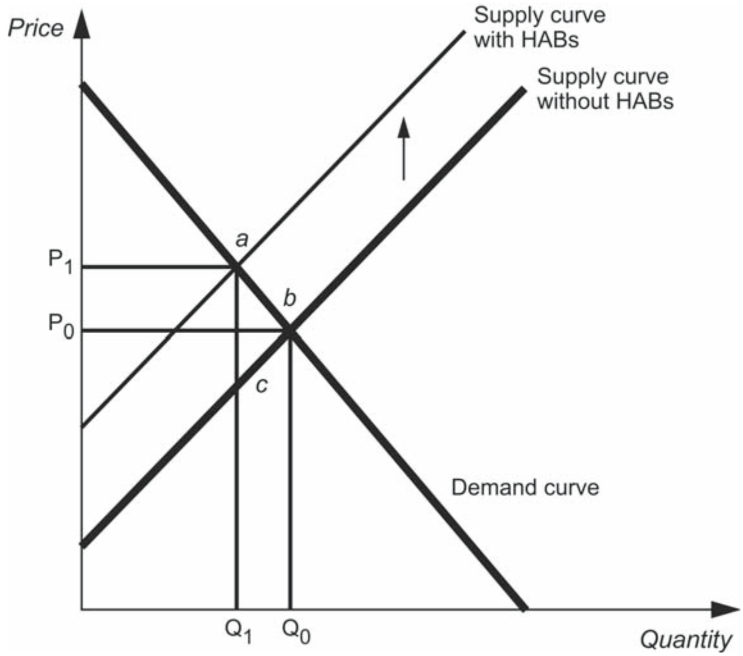

Fig 30.2. A model of the market for shellfish showing changes in consumer and producer surplus before and after a closure due to a HAB event. Closing a portion of the shellfishery results in a contraction of the supply of shellfish to the market (from Q_0 to Q_1), represented by a shift up in the supply curve. The price of shellfish increases as a consequence, rising from P_0 to P_1. All consumers and some producers are affected adversely by the closure

on producer surplus is given by the area P_1ae minus area P_0bd. The change in social welfare is given by area *abc*.

Because surplus changes are apparent only in established markets, economists must first identify the relevant markets that may be affected by HABs. In the case of HABs, these markets typically are linked closely to human activities along the coast or in the ocean. Thus the relevant markets include those for seafood, especially shellfish; labor, in the event of unemployment, morbidities, or mortalities; coastal tourism, including shoreside businesses that benefit from coastal tourism. Economists also recognize that there may be losses associated with the adverse effects of HABs on environmental features, such as marine mammal mortalities, some of which are not traded in established markets. For such losses, economists would still want to measure changes in surplus, but they must do so by looking at changes in real markets that are linked to the environmental features or by modeling hypothetical markets.

One of the earliest examples of a study of surplus losses is one that focused on the consequences of a bloom of brown tide (*Aureococcus anophagefferens*) in 1985 in the Peconic Bay, located on Long Island, New York. The brown tide resulted in the complete loss of an important bay scallop (*Argopecten irradians*) fishery in that estuary. Subsequent efforts to restore bay scallops to the Peconic have met with little success. Kahn and Rockel (1988) estimate annual surplus losses in this fishery on the order of $3 million (2005 dollars). Because this fishery has not been re-established, this loss has been incurred annually for the last two decades.

A more recent study examines economic losses associated with HABs that lead to a wider range of effects, including noxious odors, fishkills, and potential public health concerns. The study was conducted at the Dutch beach resort, Zandvoort, near Haarlem, The Netherlands. Using survey techniques that simulate a market, Nunes and van den Bergh (2004) estimated that tourists might be willing to pay a lump sum between $200 to $300 million (2005 dollars) over 2 years for requiring merchant vessels to treat their ballast waters and for water monitoring programs to protect the beach. Because these programs would mitigate the adverse effects of HABs, they can be interpreted as crude estimates of the scale of economic losses from a red tide at Zandvoort.

A third example concerns an estimate of economic losses associated with the phenomenon known as the "halo effect". A halo effect occurs when economic losses are collateral to (but not directly the consequence of) a HAB event. The origin of the term "halo effect" is somewhat obscure, but it appears to have been first used about 30 years ago by Jensen (1975) in reference to "food scares," such as that associated with a 1972 bloom of *Alexandrium tamarense* in the US Gulf of Maine. Examples of halo effects include reduced consumption of all seafood (not just shellfish), fewer tourist visits to areas known to be experiencing a HAB event, among others. In 1997, a halo effect was measured as the consequence of a bloom of *Pfiesteria piscicida* that resulted in fish kills – mainly of menhaden (*Brevoortia tyrannus*) – along the Maryland coast of Chesapeake Bay. Because of the coincidental appearance of physical and neurological problems in some fishermen, then Maryland Governor Parris Glendening stated publicly that people could be hurt by *Pfiesteria*, and he prohibited recreational and commercial fishing in several Chesapeake tributaries. These actions resulted in lost sales to seafood producers in most seafood categories, including those clearly unrelated to the *Pfiesteria* bloom. A study of the halo effect concluded that the public announcement of a fish kill leads to reductions in demand for seafood. As part of that study, Whitehead et al. (2003) estimated surplus losses to seafood consumers in the mid-Atlantic region of the United States at between $37 and $72 million in the month following the *Pfiesteria* bloom (an important conclusion of the Whitehead et al. (2003) study is that public pronouncements assuring the safety of seafood do little to reduce economic losses. More effective are mandatory programs of seafood inspection).

To date, there have been only a few studies of changes in economic surplus as a consequence of HAB events. There may be many reasons why only a few extant studies exist. These reasons include the lack of data, the low frequency of events in many regions, and the small and localized scales of many events. We conjecture that one of the most important reasons may be the relatively high cost of conducting some types of economic surplus loss studies, particularly those involving the modeling of hypothetical markets. As the scale of the losses resulting from HABs becomes more apparent, and as their frequency increases, we expect that more studies will be forthcoming.

30.6 Economic Impacts

In many instances, crude estimates of economic effects known as “economic impacts” are presented as a measure of the losses associated with HAB events. For example, an estimate of the lost sales of shellfish in Maine and Massachusetts due to closures imposed as a consequence of the 2005 *Alexandrium* bloom is about \$ 2.7 million for the month of June. Such an estimate is obtained by examining historical statistics on shellfish harvests and aquaculture production and multiplying by the market price. An economic impact estimate such as this does not measure changes in economic *value* as defined above (viz. Propst and Gavrilis 1987). Nevertheless, estimates of economic impacts can be useful for at least three reasons. First, they are easy to make. Second, they give us a general idea of the scale of the problem in familiar monetary units. Third, they can help us to identify the relevant markets and geographic locations in which economic losses potentially occur.

Estimates of economic impacts can be misleading in various ways, however. Strictly speaking, economic impacts are not measures of surplus changes, and therefore they should not be used to help decide on the most efficient ways in which to respond to HAB events. Under quite normal market conditions, estimates of economic impacts might well exceed estimates of producer surplus losses. Further, estimates of economic impacts do not account for shifts in the distribution of surpluses. For example, a HAB closure might result in the reduction of the supply of softshell clams to the market. As a consequence, we would expect the price of clams to rise. Those firms that are prevented from harvesting clams will experience a loss of producer surplus. Other firms that are harvesting in other open areas, however, may reap more of a surplus because of the price increase. These higher producer surpluses will come at the expense of consumers, who are forced to pay the higher price. These consumer surpluses are not really lost to the economy; they are just transferred from consumers to those firms who remain in the market. Moreover, those producers who are closed out of harvesting do not have to incur harvesting costs. Reports only of economic impacts do not capture all of the subtleties of these shifts in surpluses.

Because of both the widespread use and the perceived usefulness of economic impact estimates, there is a considerable risk that they will be employed to argue for the scale of management responses to HABs. Indeed, such estimates crop up in policy debates over and over again. One classic example concerns an estimate of the surf clam (*Spisula polynyma*) resource in the Bering Sea off the coast of Alaska (Anderson et al. 2000). In 1997, upon introducing the US Harmful Algal Bloom Research and Control Act (S. 1480) (a substitute version of this bill, the “Harmful Algal Bloom and Hypoxia Research and Control Act” [P.L. 105-383] was enacted in 1998) in the US Senate, Senator Olympia Snowe (R-ME) noted that $50 million worth of Alaskan “shellfish resources” remain unexploited because of paralytic shellfish poisoning (PSP) toxicity. This estimate actually emerged in the late 1970s following the results of a US government survey of potentially exploitable quantities of the surf clam in the Bering Sea, and it has reappeared in several policy contexts over the years. Other reasons for the lack of an Alaskan surf clam fishery may be equally or more compelling than the presence of PSP toxins, including the fact that the fishery is unlikely to be commercially viable even in the absence of PSP, a need to protect juvenile spawning grounds for the red king crab (*Paralithodes camtschaticus*) in the same area as the surf clam stock, and concerns expressed by indigenous peoples over the potential impacts of a clam fishery on walrus (*Odobenus rosmarus*) stocks. The act passed without any discussion or apparent concern with the basis for the impact estimate.

30.7 Estimates of National Economic Effects

The EU and the US represent two good examples where estimates of aggregate national level economic effects from HABs have been attempted. Table 30.1 shows roughly similar estimates of broadly defined economic effects of HABs from both the EU and the US. These estimates fall into similar categories, but they have been developed using different methodologies.

Here we present in general terms the nature of the estimates in each of the categories in Table 30.1. Estimates from each of these categories and the totals should be viewed as only very rough estimates of the scale of annual economic effects. We also normalize the estimates by calculating economic effects per kilometer of shoreline, with the caveat that HAB effects are not uniformly distributed either geographically or over time. The US estimates are averaged over the 14-year period from 1987 to 2000; the EU estimates are averaged over the 10-year period from 1989 to 1998. The estimates in Table 30.1 for the US are an unpublished update of earlier estimates reported in Hoagland et al. (2002) and Anderson et al. (2000). This update employs the same methodologies but it averages economic effects over a longer period:

Table 30.1. Estimates of the average annual economic effects of HABs in the European Union and the United States (2005 dollars)[a]

	EU ($\$ \times 10^6$)	US ($\$ \times 10^6$)	EU (\$/km)	US (\$/km)
Public health	11	37	170	1,856
Commercial fisheries	147	38	2,243	1,912
Recreation and tourism	637	4	9,743	225
Monitoring and management	18	3	273	169
Total	813	82	12,429	4,162

[a] The potential comparability of these estimates is discussed in the text. Values for Europe have been adjusted using an average foreign exchange rate of € 1.13/$1.00 for the year 2003. Values in both columns were converted into 2005 dollars using the US consumer price index. Values in the latter two columns were normalized by dividing by coastline length (65,414 km for the European Union and 19,924 km for the United States)

1987–2000. Estimates from both jurisdictions give us a sense of the scale of average economic effects on an annual basis. We encourage the reader who is interested in more detail on the development of these estimates and their interannual variability to refer to the original publications (Scatasta et al. 2003; Hoagland et al. 2002; Anderson et al. 2000).

The estimates in Table 30.1 have been arranged into four distinct categories. The first category, public health, relates to the costs of morbidities or mortalities that result from eating shellfish contaminated with either PSP, diarrhetic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), or neurotoxic shellfish poisoning (NSP) or from eating finfish contaminated by ciguatera fish poisoning (CFP). Estimates from each jurisdiction are directly comparable; they employ the same factor to measure the economic impacts of lost productivity (sick days), medical treatments, transportation, and causal investigations. Some minor adjustments are made to distinguish reported from unreported illnesses, and rules-of-thumb are applied to estimate the numbers of the latter. In both jurisdictions, health advisories and fishery closures have reduced greatly the direct economic impacts during the last decade, at some (unknown) cost of halo effects. In the US, the public health effects are dominated by CFP illnesses in tropical jurisdictions, which unlike outbreaks of the other toxins, occur on a continuous basis. In the EU, the public health effects are dominated by DSP illnesses especially in Belgium, France, and Spain. Neither estimate includes the personal (non-market) costs of pain and suffering associated with morbidities.

The second category, commercial fisheries, relates to closures of shellfisheries and aquaculture operations, mortalities of shellfish or fish in aquaculture operations, prohibitions on the commercial sale of recreational fish (due to CFP), untapped fishery resources (fisheries that are arguably viable but that cannot be opened due to HABs), and halo effects, including those that might be precipitated by government policies or pronouncements. Notably, the estimate of annual economic effects in European commercial fisheries are roughly four times greater than those in the US. Estimates from both jurisdictions are not directly comparable, however, as they result from the application of different methodologies. In Europe, the estimate represents the midpoint of a range of combined consumer and producer surpluses. Notably, losses of consumer surplus due to lower perceived quality of shellfish represent 75 % of the total loss in economic surpluses. The relationship between HAB closures and reduced production of shellfish (blue mussels, *Mytilus galloprovincialis*) is apparent only in Galicia, Spain, which produces 18.5 % of the world's supply of aquacultured mussels (data on EU shellfish production can be found only at the national level, while data on harvest closure days are reported at the local level. This mismatch makes the analysis of the relationship between harvest closure days and shellfish production quite difficult. Spain, due to its highly geographically concentrated shellfish production, was the only country for which such a mismatch did not occur).

The European estimate includes also the effects of an EU directive on seafood quality, which benefits producers in France and Ireland and hurts producers in Spain and Italy, as European consumers switch to perceived higher quality mussels. In the US, the estimate is primarily an economic impact estimate (e.g., lost sales). Untapped surf clam resources in Alaska and on Georges Bank may account for as much as one-third of this estimate. The latter estimates do take into account the potential effects of the increased supply of shellfish on the relevant market. Ongoing work on halo effects, as described above, probably would augment the estimate of economic effects in the United States.

The third category represents effects of HABs on recreation and tourism in Europe and the United States. The European estimate is the result of a series of four surveys of coastal tourists in Italy, Ireland, Finland, and France (Scatasta et al. 2003), and is to be interpreted as a measure of potential damages in the EU if conditions found in the surveyed locations were representative of conditions in the EU as a whole (to obtain the European estimate, average economic losses per tourist in surveyed locations were multiplied by the total number of coastal tourists in the EU. Surveyed locations included two areas of high occurrence of HABs (Italy and Finland), one area of medium occurrence of HABs (Ireland) and one area of very low or no occurrence of HABs (France). The surveys attempt to measure the diminished experience of coastal tourism during a HAB event (a "non-market" consumer surplus loss). These surveys reveal that economic losses from HAB events depend upon both the level of tourist income as well as the familiarity of tourists with high-biomass, non-toxic algae blooms (i.e., those causing discoloration of the ocean, high volumes of foam, noxious odors, or bathing beach closings). In particular, these non-market losses were found *not* to be a function of blooms of toxic algae, perhaps because the surveyed tourists were able to substitute foods more easily than destinations. In contrast to Europe, estimates of non-market losses to tourists from HAB events in the United States are markedly absent. The US estimate in Table 30.1 relies mainly upon an incompletely documented economic impact estimate for a 1987 bloom in North Carolina and estimates of reduced expenditures for razor clamming (*Siliqua patula*) in the state of Washington. To date, attempts to account for either surplus losses or the economic effects of blooms of *Karenia brevis* along the Florida coast of the Gulf of Mexico have been mostly inconclusive, with some evidence of reduced beach visitation during a bloom event in certain areas (Adams et al. 2000).

The final category pertains to monitoring and management costs. The values from both jurisdictions in this category are roughly comparable estimates of economic impacts. The estimate for the EU is based upon data from Ireland, Spain, and The Netherlands, which is used to develop an estimate of monitoring and management costs per kilometer of coastline. This unit cost is then used to develop estimates of costs for other EU countries. The estimate for the US, which is an order of magnitude smaller, is based upon data obtained directly from state governments, where no assumptions are made about expenditures in states where no data exists. Government expenditures on scientific research on HABs would fall into this category, but they are included in neither estimate. An interesting interpretation of monitoring and management costs is that, unlike the estimates in other categories, they represent crude estimates of the costs of policy responses to HABs.

30.8 Conclusions

Much work remains to develop reliable estimates of the economic effects of HABs. As this work proceeds, attention should be directed at the rationale for developing these estimates. While government officials and others might solicit economic estimates of any kind in order to justify idiosyncratic public health or scientific agendas, attention should be directed at developing estimates of true economic losses, i.e., surplus changes. Based upon our experience with the field, although the number of studies of economic losses or impacts is limited, they outnumber studies of the economic costs of societal responses to HAB events. In other words, societal responses to HABs have been debated, formulated, and implemented with an inadequate understanding of the net benefits of such responses. Further efforts on the economics of HABs should focus on identifying the array of societal responses and characterizing the cost minimizing combination of management actions.

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References

Adams CM, Mulkey D, Hodges A, Milon JW (2000) Development of an economic impact assessment methodology for occurrence of red tide. SP 00-12. Inst Food Agric Sci, Food Resource Econ Dept, Univ Florida, Gainesville, Florida, 58 pp

Anderson DM, Hoagland P, Kaoru Y, White AW (2000) Estimated annual economic impacts from harmful algal blooms (HABs) in the United States. WHOI-2000-11Woods Hole Oceanogr Inst, Woods Hole, Massachusetts. http://www.whoi.edu/redtide/pertinentinfo/Economics_report.pdf

Hoagland P, Anderson DM, Kaoru Y, White AW (2002) The economic effects of harmful algal blooms in the United States: estimates, assessment issues, and information needs. Estuaries 25:677–695

Jensen AC (1975) The economic halo of a red tide. In: LoCicero VR (ed) Proc 1st Intl Conf on Toxic Dinoflagellate Blooms. The Massachusetts Sci Technol Found, Wakefield, Massachusetts, pp 507–516

Kahn JR, Rockel M (1988) Measuring the economic effects of brown tides. J Shellfish Res 7:677–682

Nunes PA, van den Bergh JC (2004) Can people value protection against invasive marine species? Evidence from a joint TC-CV survey in the Netherlands. Environ Resour Econ 28(4):517–532

Propst DB, Gavrilis DG (1987) Role of economic impact assessment procedures in recreational fisheries management. Trans Am Fish Soc 116:450–460

Ramsdell JS, Anderson DM, Glibert PM (eds) (2005) Harmful algal research and response (HARNESS): a national environmental science strategy. Ecol Soc Am, Washington, DC, 82 pp

Scatasta S, Stolte W, Granéli E, Weikard HP, van Ierland E (2003) The socio-economic impact of harmful algal blooms in European marine waters and description of future risks. ECOHARM project, 6 FP, EU. Environ Nat Resour Group, Wageningen Univ, Wageningen, NL http://www.bom.hik.se/ecoharm/index.html

Van den Bergh JC, Nunes PA, Dotinga HM, Kooistra WH, Vrieling E, Peperzak L (2002) Exotic harmful algae in marine ecosystems: an integrated biological-economic-legal analysis of impacts and policies. Mar Policy 26:59–74

Whitehead JC, Haab TC, Parsons GR (2003) Economic effects of *Pfiesteria*. Ocean Coast Manage 46:845–858