From Jubilees to Halos:

Clarifying the Economic Effects of Harmful Algal Blooms (HABs) on Commercial Fisheries

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Abstract

Harmful algal blooms (HABs) are widely thought to have negative economic effects on commercial fisheries. Over the years, many studies have been carried out to estimate these effects, using a variety of methodologies, from simple to complex. While some of these studies are useful, many others ignore some of the important characteristics of the biology of fish stocks, the behavior of firms in the harvesting sector, the exvessel markets for fresh or partially processed fish, and the characteristics of wholesale markets and markets of substitute seafood products. Accounting for these important features of fisheries can make a difference in terms of the occurrence and scale of economic effects. Further, in order to develop appropriate mitigation strategies, it is important to characterize correctly the size and distribution of economic effects. In this paper, I present an overview of some of the most important considerations when undertaking estimates of the economic effects of HABs on commercial fisheries. I discuss fishery closures, untapped resources, capital and labor malleability, processing costs, halo effects, and some of the issues of efficiency and distribution that arise in these contexts. I illustrate the discussion using real-world examples from HAB-impacted fisheries around the nation. I conclude with some recommendations for estimating the economic impacts of HABs in commercial fisheries in the future.

Introduction

In April 1997, a jubilee[1] of kreef (*Janus lalandii*), an edible species of rock lobster, occurred in Elands Bay, north of Cape Columbine, along the coast of the Western Cape province of South Africa. As the consequence of the biological breakdown of dieoff from a significant bloom of *Mesodinium rubrum*, a ciliated algae, thousands of kreef migrated shoreward to reach oxygenated waters in the surf zone. As the tide receded, an estimated 1,360 mt of kreef became stranded on the shore. News reports cited the price of kreef in restaurants ($48/kg), suggestive of an economic "loss" on the order of $65 million from the jubilee. The scene was repeated in April of 1999 (100 mt at $25/kg: an estimated $2.5 million loss) and February 2002 (1,000 mt at $15/kg: an estimated $15 million loss).[2]

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[1] A "jubilee" is a term that originated in the southern United States, probably in eastern Mobile Bay, Alabama, to describe the phenomenon of an unpredictable migration of fish into near shore waters or onto the shore. The cause of a jubilee is most likely the development of hypoxic conditions during the microbial decomposition of algae after a dense bloom.

[2] Not all of the beached kreef were wasted. At the time of the first jubilee, hundreds of people came down to the shore to collect the kreef for personal consumption. While fishermen might consider this to be a loss, this type of harvest is essentially a transfer of the economic value of the collected kreef directly to the consumer. As a consequence, the sudden, ready availability of fish ought to be considered the product of a "beneficial" algal bloom (in the sense of the term "jubilee") and not a "harmful" algal bloom. Further, municipal authorities attempted to move some of the kreef to oxygenated waters further down the coast. It is unknown how many kreef were collected for consumption or successfully transferred by these methods. Because of damage to coastal properties that occurred during a scramble for kreef at the first jubilee, public

Back-of-the-envelope estimates of economic impacts such as these are commonly found when blooms of "harmful" algae lead to fishkills or the closure of commercial fisheries.[3] While such estimates attract the attention of policy-makers and the public, they may misrepresent actual economic effects. For example, whether jubilee kreef actually would have supplied the commercial fishery seems unlikely, as the focus of the kreef fishery is located well to the south of Elands Bay. Further, *Mesodinium* blooms are a natural phenomenon, representing only one source of non-fishing mortality of kreef. It is not clear that jubilees lead to significantly higher levels of natural mortality, adversely affecting stock recruitment. Although kreef stock size has dwindled in recent years, fishery scientists have suggested that this may be the consequence of the combination of persistent overfishing[4] and coast-wide reductions in the growth rate (Melville-Smith and van Sittert 2005). Consequently, a closer examination of the details of the

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policy now prohibits the collection of jubilee kreef for personal consumption. Unless kreef can be transferred successfully to oxygenated waters, this policy ironically may increase the potential for economic loss during a jubilee.

[3] Economic impact estimates of all types are reported in Anderson *et al*. (2000). Some of the issues to be considered in assessing different types of impacts are outlined in Hoagland *et al*. (2002).

[4] An argument could be made that commercial overfishing has caused the kreef stock to become more susceptible to catastrophic environmental events, such as HABs. In this sense, an additional cost of overfishing is the expected reduction in future stocks should a significant proportion of the existing stock be lost because of a jubilee.

kreef fishery imply that rough estimates of economic impacts ranging into the tens of millions of dollars are likely well overstated.

Ideally, economists would prefer to develop measures of lost economic *surpluses* that result from the occurrence of a marine natural hazard such as a HAB event. Van den Bergh *et al*. (2002) review the methodology from welfare economics for measuring lost surpluses from marine natural hazards like HABs. Surpluses comprise what consumers are willing and able to pay in excess of the market price and what producers earn in revenues that exceed their costs, with the latter potentially including a resource rent, given appropriate institutional incentives. This perspective on social impacts differs markedly from the perspective taken by natural scientists, who may be concerned mainly with ecological changes, including changes that involve components of an ecosystem for which market prices are unavailable or difficult to determine (*viz*., Hoagland and Scatasta 2005). While both perspectives arguably have a role to play in decisions about appropriate societal responses to natural hazards, and in fact these roles may be complementary, it is important to present and interpret data about environmental changes using theoretically valid approaches.

Only a few studies have developed estimates of lost surpluses resulting from HAB events. In an early example, and still one of the best applications to date, Kahn and Rockel (1988) calculate total surplus losses of about $3 million per year from the elimination of commercially exploited bay scallop (*Argopecten irradians*) stocks as a consequence of brown tide (*Aureococcus anophagefferens*) blooms in the Peconic Estuary at the northeast end of Long Island, New York. This particular bloom is a persistent one, signifying hysteresis, and leading to enduring economic damages.[5] Too, this study is an important, but rare, example of the kind of analysis that could be used to help policymakers justify an efficient management response to HABs. In this case, as in others, however, it has been difficult to find and implement successful management responses, because the true cause of the brown tide is uncertain.[6] Most HABs are a true *natural* hazard, and the economic damages that arise when harmful algae bloom involve the displacement of human uses of the ocean, either as a consequence of the bloom or due to human actions to mitigate its adverse effects.

In the following sections, I explore some examples of HAB-impacted fisheries from the United States in order to begin to understand the extent to which estimates of economic losses are relevant and useful for policy-making. Using a qualitative approach, I discuss the relevance of rough estimates of economic costs, showing that such estimates often overstate the true costs. By means of these illustrations, I briefly consider issues concerning fishery closures, the timing

[5] This example differs from the example of "untapped" resources, discussed below, in that the bay scallop fishery had been commercially viable prior to its preclusion by the blooms of brown tide. In the case of untapped resources, or potential fisheries that have never been prosecuted, commercial viability in the absence of HAB events is an open question.

[6] One hypothesis points to anthropogenic releases of macronutrients, especially nitrogen, as the cause of the brown tide blooms in the Peconic. While nutrients certainly play a role in bloom formation, their presence does not explain why *Aureococcus* is favored instead of some other less harmful, or even more beneficial, algae. In general, the possibility of HABs being caused by human pollution changes the mix of possible management responses. Where hysteresis has occurred, even if anthropogenic nitrogen is identified as the cause, there may be significant costs involved in restoring the ecosystem back to its former condition.

of impacts, untapped resources, capital and labor malleability, processing costs, halo effects, and some of the issues of efficiency and distribution that arise in these contexts. I conclude with some recommendations for reporting on and developing appropriate models for estimating the economic impacts of HABs in commercial fisheries in the future.

Fishery Closures

The most common management response to the onset of a bloom of toxic algae[7] is to close an affected fishery for a period of time. The main purpose of a closure is to protect the public health; a closure is a blunt, but effective, tool for preventing tainted shellfish from entering the supply chain, being consumed, and causing human intoxications that lead to morbidities or mortalities. Fishery closures normally apply to shellfisheries, as finfish do not tend to accumulate algal toxins. State coastal resource managers systematically sample and analyze shellfish from commercial beds, closing the beds when HAB toxin levels exceed a threshold level. A typical analysis of economic impacts examines historical shellfish yields from closed areas, calculating losses as the product of average annual yield over some recent period of time and market price. A good example concerns the large number of closures along the coast of Maine during September 1980, leading to an estimate of economic impacts of $2.4 million in that year (communication with natural resource managers at Maine DMR, as reported in Anderson *et al*. 2000).

This method of evaluating economic impacts is both empirically and theoretically problematic. For example, Anderson *et al*. (2000) attempt to relate aggregate shellfish yields to

[7] Algal toxins that contaminate shellfish ("shellfish poisons" [SP]) are of four main symptomatic types: paralytic (PSP), diarrhetic (DSP), neurologic (NSP), and amnesiac (ASP).

shellfish closures in Maine and Massachusetts during 1987 to 1992 due to blooms of *Alexandrium fundyense*, an organism that produces the paralytic shellfish poisoning (PSP) toxin. Contrary to expectations, these authors find increased shellfish outputs during the years with the most extensive HAB closures. One reason for this finding may be the ability of shellfishermen to switch easily to those commercial beds that remain open[8] in order to supply the market when closures are put in place.

More recent studies have focused in on the relationship in Maine and Massachusetts between HAB-induced closures and shellfish yields at local (county or municipal) levels. Downeast diggers in Washington County, Maine were the recipients of $2 million in emergency response funds after the state made a case that closures implemented during the extensive 2005 *Alexandrium* bloom were tanatamount to a disaster. Jin *et al*. (2007) examine data at the county level in Maine and the municipal level in Massachusetts, finding an upper bound on aggregate regional lost sales on the order of $20 million from the same bloom ($18 million in Massachusetts and more than $2 million in Maine). The local focuses of such studies tend to ignore gains to suppliers in areas outside of the accounting stance that remain open, including hard clam (*Mercenaria mercenaria*) and Eastern oyster (*Crassostrea virginica*) diggers and growers down the entire Atlantic coast.

These studies focus also on lost sales (gross revenues), a measure that ignores the fixed and variable costs of fishing. Notably, variable costs would not be incurred if diggers do not

[8] It is possible that these beds are initially more productive, as they may be subject to less fishing pressure when the preferred beds are open in the absence of a HAB closure.

work, thereby reducing economic losses.[9] Further, these fisheries tend to be subject to regulated open-access management measures, enforced at the municipal level, although there may be some barriers to entry that apply to out-of-town diggers. This institutional arrangement suggests that resource rents are likely to be small.[10]

Local losses may be offset by gains to shellfish producers in areas that remain open, from Rhode Island south to Florida. For example, in the Jin *et al*. study, the authors discover increased prices for softshell clams (*Mya arenaria*) in the New York Fulton market, suggesting that gains may have accrued to suppliers in other regions during the Gulf of Maine event. All three issues, while certainly deserving of further study, imply that the use of lost sales as an estimate of economic impacts probably overestimates the economic losses.

In markets exhibiting inelastic demand, consumer surplus losses will occur because of price increases when supply is reduced as a consequence of a HAB event. And some consumers will be unwilling to purchase shellfish at the higher prices. The possibility of consumer surplus losses make it less likely that economic losses will be overstated when the lost sales measure is

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[9] The economic consequences to aquaculture operations may differ from those felt by shellfish diggers, as they may incur both fixed and variable costs in advance of a HAB-induced closure. (See the discussion on the timing of management responses below.) In general, it is sensible to look at the specific characteristics of the production technologies and the market in order to fully comprehend the nature of the economic impact.

[10] Townsend (1985) shows that yields per digger-day increase for very restrictive limited-entry programs (depuration licenses) in the Maine softshell clam industry. Existing locally restricted access programs provide only about one-quarter of the benefits of the very restrictive limited entry programs.

employed, although losses to consumers will not have been accounted for explicitly. Note also that some of the consumer surpluses will be transferred to those producers who are able to continue to supply the market. Understanding the scale and incidence of surplus changes would require the development of a model of the market for shellfish.

Biological Dynamics

From a bioeconomic perspective, the closure of shellfish beds due to HABs is similar to the establishment of a temporary fishery reserve. This observation may apply to some commercial species and not others, as shellfish differ in their sensitivity to harmful algae, with some species, such as blue mussels (*Mytilus edulis*), more-or-less indifferent and others, such as the Eastern oyster, whose growth may be hindered (Bricelj and Shumway 1998).[11] Following this line of argument, the closure of some shellfish beds would allow individuals to grow larger and exploited stocks to rebuild. In addition, larvae from the stocks in the closed areas potentially could diffuse into areas that remain open, perhaps at increased rates.

These effects may either reduce the losses associated with closures or, in some cases, lead to net benefits, particularly in cases of overexploited stocks. It is important to recognize, however, that, without complementary regulation to rationalize fishing effort, the *per se* implementation of fishery reserves is unlikely to solve problems of economic overexploitation. Nevertheless, if the fishery is managed efficiently in the areas that remain open, the potential

[11] Shellfish species vary in their sensitivity to HAB toxins and, because of behavioral responses (shell clapping) or feeding rates, the extent to which they accumulate HAB toxins (Bricelj and Shumway 1998). Many shellfish species appear virtually unaffected by HAB toxins, and when a bloom of toxic algae occurs, they continue to feed on algae as one source of food.

exists for producer surplus gains—in the form of resource rents—to exceed consumer surplus losses (Sanchirico and Wilen 2002). One caveat to the fishery reserve argument is the often sporadic nature of the closures; it is possible that HAB-related closures may not exist for a long enough period of time for either refuge or stock effects to be realized.

Timing of Management Responses

The incidence and scale of economic impacts from HAB events depends critically upon both the occurrence of the hazard and the timing of the management response. For example, if a closure has been imposed on a fishery in a certain location, then fishermen will not go fishing, and the variable costs of fishing will not be incurred. Moreover, depending upon the malleability of capital and labor (see the discussion below), fishermen may be able to reduce any losses by switching to other fishing locations, other fisheries, or other occupations.

Once shellfish have been harvested, if, after testing, the product is prevented from reaching the market because its toxicity exceeds safe levels, then an appropriate measure of loss is the sum of lost surpluses and harvesting costs. In this situation, economic losses rightfully include harvesting costs because they are a measure of resources that were utilized to no productive effect. Consequently, if demand is elastic, and consumer surpluses are likely to be small, then an estimate of lost sales is an appropriate measure of economic losses from already harvested product.

Real world examples include $500,000 in lost sales of European oysters (*Ostrea edulis*) shipped from Maine growers to The Netherlands in 1988, when the product was unable to be sold after testing positive for diarrhetic shellfish poisoning (Shumway 1990), and dieoffs in 1987, 1989, and 1990 of cultured Atlantic salmon (*Salmo salar*) in Washington State, when the fish suffocated after their gills were clogged with mucous in response to a bloom of *Heterosigma akashiwo* (Horner *et al*. 1991). Other legitimate economic losses include those affecting coastal aquaculture facilities that subsequently must incur additional delay, depuration, or disposal costs, including elevated tipping fees for the disposal of tainted product.

Untapped Fisheries

Some prospective fisheries arguably are commercially exploitable, but their potential value remains untapped in the presence of HABs. A classic example concerns the surf clam resource of coastal Alaska (*e.g*., Neve and Reichardt 1984), which has been held up as a prominent example to justify the need for national policies to study and respond to HABs as a natural hazard. According to the legislative history to the US Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, an estimated $50 million in annual shellfish yields in Alaska's Bering Sea is potentially commercially exploitable. Because Alaska has not approved shellfishing in the Bering Sea according to National Shellfish Sanitation Program standards, harvesting this resource is currently infeasible, and thus it has been touted as a cost of HABs.

One probable source for this estimate begins with a 1977 National Marine Fisheries Service survey of the southeast Bering Sea, which revealed potentially exploitable quantities of the Alaskan surf clam (*Spisula polynyma*) there. Hughes and Bourne (1981) estimate an annual maximum sustainable yield (MSY) of about 25,000 mt for this resource. Relying on this MSY estimate, Lutz and Incze (1979) assess the annual potential sustainable revenue from Alaskan surf clams at $28 to $47 million. The $50 million figure quoted above is most likely a (rounded-off) reporting of the high-end of this estimate.

An analysis of the price effects of supplying about 25,000 additional mt to the US surf clam market (Hoagland 2006), which attempts to control for prices in substitute markets, suggests that the low end of the Lutz and Incze estimate is more relevant for Alaska, because the nationwide price of surf clams would be driven down by the increase in supply (Fig. 1). The analysis predicts that lost sales in a prospective Alaskan surf clam fishery would have been only about $30 million (1997 dollars) at the time of the Congressional debate over the legislation in 1997.[12] In recent years, the potential value has continued to decline even more as yields have picked up from the mid-Atlantic fishery as it recovers from earlier over-exploitation.

The suggestion that a surf clam fishery in Alaska might exist if the HAB closure were to be removed, however, is purely conjectural, relying upon a number of critical assumptions (Hoagland *et al*. 2002). In order for such "lost opportunities" as the Alaskan surf clam fishery to be counted legitimately as economic effects, the fishery must be shown to be commercially viable (Foster 1997). Certainly, the price effects of the production of surf clams at the MSY

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[12] The analysis relies on a model of price prediction in the surf clam fishery. The model is specified as $P_{\text{surfclams}} = f(Q_{\text{surfclams}}, P_{\text{ocean quahogs}}, P_{\text{hardclams}}, P_{\text{eastern oysters}}, Y_{\text{disposable personal income,}}\ \varepsilon)$. The model uses monthly data from 1991 to 2004 (168 observations) in a log-log functional form. All coefficients are significant at the 5% level or better; adjusted R^2 is 45%. Further details are available from the author. In calculating the likely value from the Alaskan and Georges Bank fisheries, an assumption is that average monthly production from the mid-Atlantic fishery does not change with price, and the Alaskan and Georges Bank fisheries produce at MSY. In reality, mid-Atlantic fishermen are likely to reduce effort (and therefore yields) due the effect of the price decrease on the value of quota; this reaction would ameliorate the price decrease itself. Consequently, our estimate of potential lost sales is conservative.

level could decrease profitability to the point that entry might be financially unviable. Further, the structure of the market may present an entry barrier into this fishery, as there needs to be a close coordination between harvesting and processing sectors in the production of surf clams due to the characteristics of the end market (*viz.*, Weninger 1998), and no shoreside processing capacity for these clams is in place in Alaska. Other possible constraints include the timing or area coverage of closures to protect juvenile spawning grounds for King crab (*Paralithodes camtschaticus*) and opposition from environmental interests regarding the potential effects on an important food source for the protected walrus (*Odobenus rosmarus*). Given that only a small proportion (two out of 185 samples) had detectable levels of PSP toxin when last tested in 1978 (Hughes and Nelson 1979), the estimates of potential economic impacts in this untapped fishery are likely overstated.

In addition to the effects in the untapped Alaskan fishery, the extra supply of surf clams would affect the existing market for mid-Atlantic surf clams (*Spisula solidissima*). As price is driven down, total sales in the mid-Atlantic surf clam fishery also would decline (due to reductions in harvests and the fall in price). Moreover, the lower price implies that the value of individually transferable quota in one of the only rationalized fisheries in the United States would decline as well.[13] The mid-Atlantic fishery potentially could lose more than $2 million a year in sales, amounting to as much as 6 percent of the market in recent years.(Fig. 2).

Capital and Labor Malleability

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[13] Thus one might well expect to see political arguments in opposition to the opening of an Alaskan surf clam fishery (or the Georges Bank component of the Atlantic fishery), possibly couched in terms of potential HAB impacts.

The ease with which capital or labor can be transferred to other productive activities during a HAB closure (the degree of malleability of these factors) affects the scale of economic impacts. A typical assumption using the lost sales measure is that, once a closure is imposed, fishermen will be unemployed and fishing vessels will be laid up. Thus the value from the fishery, which provides an income to fishermen and a return to capital, would be completely lost.

Informal discussions with fishermen and growers in the Gulf of Maine suggest that HAB closures do impose costs, but shellfish producers respond to closures in a number of ways in order to minimize economic impacts. For example, it may be costly, but not completely unprofitable, for fishermen to steam to another fishing ground or to re-rig their boats for another target stock when a HAB closure has been declared. Alternatively, given advance notice of a pending closure, diggers will fish harder (also more costly), or they will seek alternative employment during the closure and wait until the shellfish depurate naturally. Consequently, here too, estimates of lost sales probably overestimate the costs of a HAB event.

Related examples include empty motel rooms or slower restaurant trade resulting from fewer tourist visits to a vacation destination during a HAB event. Motels and restaurants cannot move with the tourists, although some of the associated labor is likely to be malleable. In 1987, a bloom of the dinoflagellate *Karenia brevis* became entrained in the Gulf Stream, traveling up the Atlantic Coast from Florida to North Carolina. North Carolina officials estimated lost tourist trade during the bloom of nearly $20 million. Analogous to the issue of HAB closures, however, tourists likely took their business to other destinations. Thus, on a regional or national level, the economic impacts may have been mitigated by gains to motels and restaurants in other places.

Processing Costs

The typical management response to a toxic algae bloom is to close the fishery until concentrations of toxins in the flesh of shellfish become lower than a threshold level to protect public health. In some fisheries, however, it may be possible to process the catch in such a way as to eliminate toxicity. Processing to remove HAB toxins does not always involve added costs, if the fish are processed for the seafood market anyway. For example, the adductor muscle of the Atlantic sea scallop (*Placopecten magellenicus*) does not concentrate the PSP toxin, and this part of the scallop is selectively removed and sold for a seafood end use in the normal course of business. On the other hand, in the Canadian maritimes, a small fishery exists for sale of the roe-on scallop product into the European market. Roe-on scallop comprises the entire body of the sea scallop and the orange-colored roe. This fishery is plagued with the risks associated with PSP toxicity, and a roe-on scallop fishery in the United States has been unable to develop in recent years because of this risk.

In other cases, processing to eliminate toxicity is possible, but it also involves added costs. For example, in Alaska, yields of razor clam (*Siliqua patula*), weathervane scallop (*Patinopecten caurinus*), and geoduck (*Panopea abrupta*) often must be processed to remove portions of the animal that may be toxic due to PSP. Ralonde (1998) estimates the costs of removing toxic viscera from geoducks in 1996 at more than $1 million. A similar approach may be feasible for Dungeness crab (*Cancer magister*) catches off the coast of Washington, Oregon, and California, although concerns have been raised about how to enforce public health requirements to ensure that processing takes place. These examples emphasize that, in certain cases, depending upon the relevant fishery, the economic costs associated with HABs need not always involve shutting down the fishery with a closure.

Halo Effects

In the examples presented thus far, the lost sales measure typically overstates the economic losses associated with a HAB event. In certain cases, another manifestation of a HAB event, the halo effect, is not fully captured in the lost sales measure, implying that the measure could understate economic losses. A halo effect occurs when demand contracts in seafood markets for species or products that have not been physically affected by a HAB event. The term may have been employed first by Jensen (1975) in reference to a "food scare," such as that associated with a 1972 bloom of *Alexandrium spp.* in the Gulf of Maine. A halo effect results from the combination of consumer ignorance and risk aversion; its occurrence demonstrates inadequate communication of the consumption and health risks associated with a HAB event.

Examples of halo effects may include a lessened consumption of all seafood, 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* resulting in fish kills, mainly of menhaden (*Brevoortia tyrannus*), in a few tributaries along Maryland's Eastern Shore of the Chesapeake Bay. Because of the coincidental appearance of physical and neurological problems in some fishermen, the Maryland government warned that *Pfiesteria* could be harmful, prohibiting 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 bloom event. Lipton (1998) estimated lost sales of $43 million during the bloom and subsequent halo period. Whitehead *et al*. (2003) estimated halo effect surplus losses to seafood consumers in the mid-Altlantic region of the United States at between $37 and $72 million in the month following the *Pfiesteria* bloom.

A study of the halo effect concluded that the public announcement of a fish kill could lead to reductions in demand for seafood. As part of that study, Whitehead *et al.* (2003) estimated the effects of information about a *Pfiesteria spp.* bloom on risk perceptions, seafood demand, and willingness to pay for a mandatory seafood inspection program. The authors found that the perceived risk of seafood consumption increased with the announcement of a HAB-related fish kill. Further, the demand for seafood decreased as a consequence of such an announcement. The study authors concluded that a mandatory seafood inspection program can lead to welfare recovery, but information announcing the safety of seafood does not.

Summary and Recommendations

In summary, unqualified estimates of economic impacts made by multiplying price times potential production may have limited usefulness or be misleading. Except in rare cases where economic losses are incurred during or after production has occurred, such estimates may give an inflated impression of the scale of economic impacts in a particular market. Further, estimates of lost sales tend to focus attention on only one market, thereby ignoring gains or losses in regional markets or markets for close substitutes.

Facile estimates of lost sales may be useful, however, in identifying a subset of the markets where impacts may be felt. Where such estimates run to the millions of dollars, they should encourage closer attention, including the development of more sophisticated models of economic impacts. Some recommendations along these lines include:

- Where a HAB event leads to the closure of a fishery, a rapid assessment could be made based upon the product of median levels of historical harvests and the current market price. This assessment should be characterized as an approximate upper bound on local economic impacts.

- Any public presentation of lost sales should be accompanied by some discussion of conditions that are likely to ameliorate or exacerbate the estimate of losses, including the availability of product from open areas or other regions, the availability of substitute products, and the extent to which fishermen are able to switch to other locations, fisheries, or occupations.
- Where conditions warrant, such as lost sales estimates in the tens of millions, more detailed models of the market should be developed, in order to estimate the true surplus losses from closures.
- In order to develop market models, data useful for econometric analysis should be compiled on a regular basis. Such data include prices and quantities (yields, imports, exports) of the affected species, similar data for economic substitutes, disposable income, fishing effort and costs, among other relevant data. Some attention might usefully be paid to the potential for transferring benefit estimates from other fisheries in order to begin to estimate economic losses.
- Where market models have been developed, they should be maintained, updated, and refined on a regular basis.
- Where HAB events lead to very large surplus losses, institutional mechanisms for limiting losses should be promoted. Such institutions include the purchase of insurance, diversification of productive capacity geographically and across business sectors, investments in science and technology, including capabilities for predicting the timing,

frequency, and spatial scale of HAB events. Adverse impacts from HAB evens are likely to be lessened substantially to the extent that such institutions are functioning.

- More work is needed to compare the benefits of the protection of public health to the management costs and the opportunity costs (lost surpluses) of closures. Compared to probabilistic estimates of expected reductions in costs-of-illness or mortalities, it is possible that most shellfish closures are economically beneficial, even if estimates of the costs of closures themselves are substantially overstated.

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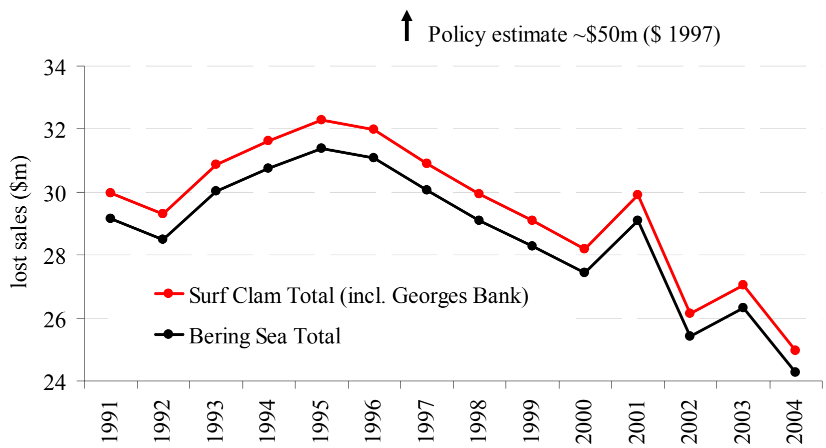

Fig. 1: Hypothetical lost sales of Alaskan surf clams for the Bering Sea and Georges Bank (Atlantic surf clams) during 1991 to 2004. The curves show the potential value of "untapped" resources based on a model of price prediction (see text). The potential lost sales are significantly lower than an estimate using MSY production levels and existing price.

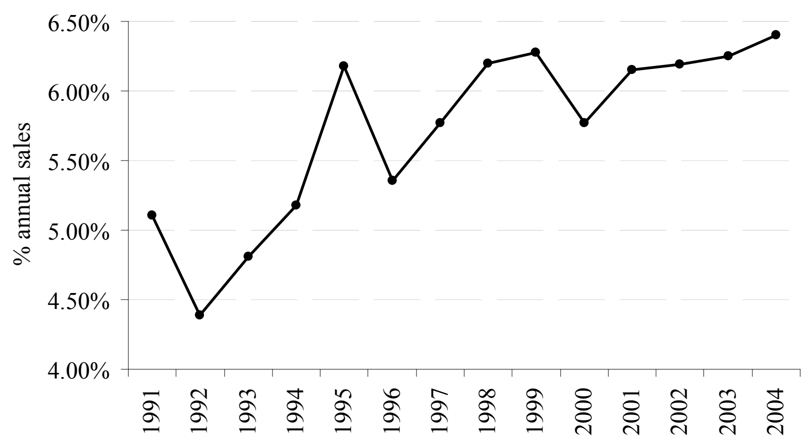

Fig. 2: Annual estimates of the percent of total sales in the mid-Atlantic surf clam fishery that would be foregone should production of surf clams occur on the untapped resources of the Bering Sea and Georges Bank. Points on the curve represent percentages of total sales due to the existing HAB closures in those regions.