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Toxic Algae Contamination and Demand for Shellfish: A Case Study of Demand for Mussels in Montreal

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Abstract *Toxic algae blooms are a worldwide phenomena, which appear to be increasing in frequency and severity. These natural events cause product contaminations that often have significant economic consequences, including supply interruptions due to closed fishing grounds, losses from human illness, and losses due to a decline in demand for the affected products. This paper evaluates the impacts of a toxic algae bloom contamination event on demand for unaffected shellfish. As an empirical example of the economic losses the shellfish industry experiences for these events, demand for mussels in Montreal is estimated using firm-level data and proxies for consumer information, during and after domoic acid contamination of Prince Edward Island mussels. Sales losses due to decreased demand are calculated. Implications of this issue for seafood safety and management policies are discussed.*

Keywords demand, shellfish, toxic algae, contamination

Introduction

In the past decade, the occurrence and severity of toxic algae blooms seem to have increased worldwide.[1] Often known as red tides (though the actual color can be red, yellow, green or brown) these blooms of phytoplankton result when di-

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[1] The occurrence of toxic algae blooms and the related impacts to shellfish has been documented for centuries (Shumway, 1990). Evidence seems to indicate that toxic blooms are increasing in frequency, intensity, duration, and geographical distribution beyond what can be attributable to improved monitoring and awareness (Shumway, 1990; Anderson, 1987). Factors affecting bloom development include: (1) nutrient enrichment, (2) changes in rates of predation on algae, (3) large scale changes in the marine/atmospheric environment, (4) storm water runoff, and (5) past bloom occurrence (Shumway, 1990). Transport of toxic algae in the ballast of ships may be accounting for the increase in global distribution of toxic blooms, and coastal pollution has been implicated as a cause or promoter of blooms (Shumway, 1990; UNESCO, 1993a). Some researchers argue that blooms only appear to be on the rise because: a) the scientific community is looking more closely at the problem; b) consumers are eating more seafood so occurrences of illness are becoming more evident; and/or c) statistical data on occurrences are improving.

noflagellates, diatoms and several other groups of photosynthetic microalgae populations rapidly multiply (Smayda, 1992). Some blooms consist of particular species of algae which produce toxins capable of accumulating in wild or aquacultured fish and shellfish. Public health threats occur when toxin concentrations in harvested fish or shellfish exceed safe thresholds.

Toxic algae blooms have occurred off the coasts of Norway, Chile, Canada, the U.S., Japan, New Zealand, India, Spain, China, and many other countries with often severe impacts to the fish and shellfish industries. Shumway (1990) lists more than 90 major incidents worldwide since the 1950s. In the U.S., toxic algae blooms have been a concern in the New England states, the Southeast coast, Texas, and along the entire West Coast, including Alaska. Substantial economic losses from algae blooms have resulted from factors such as closed fishing grounds, human illness and decreased demand for both affected and, in some cases, unaffected seafood products.

Past research on the economic impacts of harmful algae blooms on the shellfish industry has focused primarily on the losses associated with the decrease in supplies as a result of shellfish bed closures and delays in re-seeding the stock (Tester and Fowler, 1990; Kahn and Rockel, 1988; Conte, 1984). Another impact of harmful algae blooms arises when these events result in public announcements warning of the dangers of consuming shellfish harvested from affected areas. Such public announcements, typically reported by the news media, generally impact the demand for associated products (Brown, 1969; Hamilton, 1972; Sherrel *et al.* 1985). If these demand impacts were limited to the affected product, for which supply has been reduced to zero until the toxicity has passed, then the economic impacts to the industry would be limited to those related to supply reduction.

Unfortunately, it is not this straightforward. Public announcements that shellfish from particular areas are toxic, and hence should not be consumed, may result in consumer fear and avoidance of that product which can spread to other related products (Swartz and Strand, 1981). Often public agency announcements specify exactly which areas are problematic. However, news media reports may not be that specific, and may even be inaccurate, creating the potential for false perceptions of elevated risk. Consumers may not be able to differentiate between safe and unsafe product, and hence, assume that all supplies are unsafe. At other times, government agencies are unsure of the scope and scale of the event, and to avoid underestimating the extent of the problem, their public announcements and unclear warnings amplify the fears and confusion. In either case, a potential result is a decrease in demand for both contaminated and uncontaminated product. This decrease in demand may continue for only a short period of time, such as a week or two, or may persist for an extended period beyond that. Decreased demand represents a potentially significant economic loss to the industry, as well as a loss of consumer welfare.

As an example of economic impacts associated with algae toxin contamination, this paper analyzes changes in demand for mussels in Montreal, Canada, following the 1987 toxic algae contamination of Prince Edward Island (PEI) mussels. Montreal, a major market for mussels, was particularly impacted by this contamination since many individuals in this area became ill from the toxin, known as domoic acid. This event was chosen for a case study out of several possibilities because: a) the contamination event was of significant scale: b) public announcements regarding a ban on the sale of mussels did not initially distinguish between affected and unaffected product; and c) high quality market data was readily available. In addition, this paper contrasts with previous studies of economic impacts of food contamination on product demand (Shulstad and Stoevener, 1978; Swartz and Strand, 1981; Smith, *et al.* 1988; van Ravenswaay and Hoehn, 1991; Brown and Schrader, 1990), which analyzed events where no illnesses were directly attributable to the contamination. Demand functions for mussels supplied by a U.S. firm, from beds not impacted by domoic acid in 1987, will be estimated as well as sales losses to this firm. These losses serve as an indicator of the potential economic impact associated with toxic algae contamination events on shellfish demand.

The first section of the paper briefly reviews the general characteristics of algal toxins, followed by a description of the Prince Edward Island event. The second section presents the theoretical framework and methodology for estimating demand functions when preferences are influenced by real and perceived adverse health impacts. This is followed by sections which summarize the econometric results and estimated sales losses. The final section of the paper discusses implications for seafood safety and management policies.

Types and Effects of Algal Toxins

Advances in science have enabled researchers to determine the nature and origin of many algal toxins. Five groups of toxins have the potential for impacting fish in North American waters (Foxall *et al.* 1990). In cold or temperate waters, three groups of chemically distinct toxins are particularly important. They are the saxitoxins and their derivatives, responsible for paralytic shellfish poisoning (PSP); domoic acid, responsible for amnesic shellfish poisoning (ASP); and okadaic acid and its derivatives, responsible for diarrhetic shellfish poisoning (DSP). In subtropical or tropical waters, the important groups are the brevetoxins, responsible for neurological shellfish poisoning (NSP); and ciguatoxin and its derivatives, responsible for ciguatera poisoning.

The saxitoxin group affects the central nervous system by interfering with the normal functioning of nerves and muscles in the human body and can result in death. The most common method of exposure to the saxitoxins is through the consumption of contaminated bi-valve shellfish such as clams, oysters, and mussels. Concentrations of saxitoxins have also been found in other seafood, including certain types of lobster (in Canada), crab (in Japan and Fiji) and herring (in Indonesia) (Todd *et al.* 1993; Kao, 1993). In the U.S., thirteen outbreaks of PSP were reported during the period 1978–1985, involving 137 cases and two deaths (National Academy of Sciences, 1991). More recently in Alaska, one woman died and eight others became ill from ingesting mussels tainted with saxitoxin (Matsen, 1994). In Canada, 100 cases in 13 outbreaks of PSP were reported in the period 1980–1989, resulting in three deaths (Todd *et al.* 1993). Deaths associated with exposure to PSP have not been reported in Canada since 1981, but there is still concern for recreational harvesters who may choose not to heed warnings (Todd *et al.* 1993).[2]

Domoic acid is responsible for amnesic shellfish poisoning (ASP), and disrupts

[2] Note that due to the general difficulty in monitoring foodborne illnesses, there may be significant under-reporting of case numbers.

normal functioning of nerve cells. Under the influence of domoic acid, victims may experience mild gastroenteritis, headaches, seizures, disorientation, and coma. Long-term effects can include short-term memory loss, and death is possible. In Canada in 1987, three people died and 107 people became ill with ASP in one outbreak associated with Prince Edward Island mussels (Kuenstner, 1991). Domoic acid was later detected in crustaceans and bivalve shellfish harvested on the coasts of California, Oregon and Washington in the winter of 1991–1992. Ten people were reported to have become ill from eating tainted razor clams harvested on the coast of Washington (Dietrich, 1992).

Okadaic acid and related toxins are responsible for diarrhetic shellfish poisoning (DSP), the symptoms of which consist of vomiting and diarrhea. Symptoms are easily confused with gastroenteritis, making the incidence of DSP difficult to monitor (Shumway, 1990). Only two cases have been documented in the United States, but over 10,000 cases have been documented world-wide since 1976. No deaths associated with DSP have been reported (Shumway, 1990).

Neurotoxic shellfish poisoning (NSP) has occurred from North Carolina to eastern Mexico (Steidinger, 1993). Symptoms include nausea, diarrhea, numbness, tingling and chills within three to four hours after consumption, and the effects normally last for a short time period (*e.g.*, 17 hours) (Tester *et al.* 1988). A bloom resulting in the production of NSP toxins occurred in the summer of 1992 in New Zealand (the first NSP reported outside the Atlantic Ocean), and resulted in 180 cases of poisoning (UNESCO, 1993b).

In all cases of toxic algae poisoning, illness is due to ingestion of tissues containing heat-resistant toxins that are not destroyed by normal cooking, and whose presence is undetectable by sensory analysis. Toxins usually accumulate in fish through the food chain, so that mature fish may contain elevated concentrations of toxins at the time of harvest (National Academy of Sciences, 1991). Toxins can remain in shellfish tissue for months, resulting in extended closure of shellfish beds to harvesting (Shumway, 1990). Rates of toxin accumulation and depuration in shellfish are a function of environmental factors (*e.g.*, temperature), algae cell numbers, and shellfish species.

Exposure to the toxin often depends upon how much of the specific fish or shellfish is eaten. In the case of some bivalves, consumption of the whole animal increases the probability of exposure. Most reports of PSP, NSP, ASP and DSP implicate such shellfish as clams, oysters and mussels, which are typically eaten whole. Common features of events involving algal toxin contamination are the difficulties in identifying the nature and source of the toxin and establishing a link between reported illnesses and algal toxins. These uncertainties can result in broad government bands, confusion within the media and elevated perceptions of health risk.

Domoic Acid Contamination of Prince Edward Island Mussels—1987

In the first observed incident of amnesic shellfish poisoning (ASP) caused by domoic acid, three people died and 107 people became ill from consuming mussels from Prince Edward Island, Canada in 1987 (Todd, 1993). As this was the first recorded outbreak of ASP, there was initially considerable uncertainty about the nature and extent of the problem. The first indication of shellfish poisoning occurred on November 22, 1987, when two people in New Brunswick, Canada were hospitalized for mental confusion and what appeared to be gastroenteritis after eating PEI mussels (Todd, 1993). On November 24, two elderly men were admitted to a hospital in Montreal after suffering from similar symptoms. In January of 1988, researchers were finally able to positively link the illnesses to a concentration of domoic acid in mussels harvested from PEI.

The negative effects on the market for mussels were not contained within the PEI area, but were felt throughout other regions of Canada and the U.S. Initial uncertainty about the extent and cause of the contamination led the Canadian government to issue warnings or bans against a wide variety of seafood from many sources. By December 8, 1987, a ban had been issued about the consumption of all mussels regardless of their origin, including the U.S. Atlantic coast (Block, 1987a). Imports of U.S. shellfish products were destroyed by inspectors from the Canadian Department of Fisheries and Oceans, despite lack of evidence showing contamination (Block, 1987b).[3]

The broad ban was issued because government officials felt they had no choice given the unknown nature and geographic range of the incident (Norris, 1988b). Fishermen and other seafood industry members complained that the ban was too broad, saying that it "will take months to repair the havoc that Ottawa's initially ambiguous warnings created in the industry" (Norris, 1988a). Firms reported as much as an 80 percent drop in their seafood business (Curran, 1987). Seafood industry representatives stated that contamination and ambiguous government warnings severely damaged consumer confidence during the normally busy pre-Christmas season (Seafood Business, 1988).

By January 6, 1988, the ban was lifted on much of Canadian Atlantic and U.S. shellfish, and by January 9, Atlantic mussels from Maine re-appeared for sale in Montreal (Norris, 1988c and 1988d). Mussels from permitted areas of Canada's Atlantic coast went on sale a week later. By January 13, areas of PEI, Nova Scotia, and New Brunswick were cleared for harvesting shellfish (Montreal Gazette, 1988). By March 2, all Canadian waters were open for harvesting (Creighton, 1988).

Total losses due to the outbreak of domoic acid in PEI have been estimated to be approximately Cdn$8.4 million (Cembella and Todd, 1993). This estimate includes losses of employment, hospitalization costs, value of deaths, costs of monitoring and testing, costs of public relations, losses to Canadian mussel growers for 1987–1988, and losses to other Canadian shellfish harvesters, wholesalers and retailers due to the total ban on sales from Atlantic waters. Losses to the Canadian mussel growers and to other Canadian shellfish harvesters, wholesalers and retailers accounted for about 50 percent of the total loss estimate. U.S. mussel growers were also impacted by this event, although there was no evident product contamination, and these losses have never been officially documented.

Theoretical Framework

To estimate sales losses due to either short-term or long-term shifts in demand for the product due to contamination, proxy variables for information must be in-

[3] Alerts issued by the FDA appeared in U.S. newspapers by December 12, 1987 (Chicago Tribune), warning consumers to avoid eating mussels, oysters, and clams from Atlantic Canada. The FDA did not include U.S. shellfish in the warning.

cluded in the estimated demand function, in addition to standard economic determinants of demand. These proxy variables should account for the extent to which information about government bans and product contamination, conveyed through the media, affect perceptions of risk, and thus, mussel demand. The theoretical basis for such a model builds upon models developed in Shulstad and Stoevener (1978); Swartz and Strand (1981); Smith, *et al.* (1988); van Ravenswaay and Hoehn (1991); and Brown and Schrader (1990).

Swartz and Strand (1981) analyze the impact of a sales ban on oysters harvested from the kepone-contaminated James River in Virginia in 1975. The authors argue that a consumer's perceived quality (Z_i) of a good (Q_i) affects that consumer's level of utility. In addition, a consumer's perception of product quality will depend in part on information (M) that a consumer obtain's about product quality (or product risk), such as newspaper articles, television news stories, in-store information and word of mouth. Thus, a consumer's utility function can be expressed as:

$$U(Q_i(Z_i(M))) \quad (1)$$

where the utility function is assumed to be quasi-concave and twice continuously differentiable.

If a product that the consumer normally purchases has been contaminated, and the consumer knows this, then the consumer must decide how to allocate income given this information. The consumer's problem then is to maximize utility subject to a budget constraint, which can be characterized by the following Lagrangean function:

$$L = U(Q_1(Z_1(M)), Q_2) + \lambda(I - P_1Q_1 - P_2Q_2 - cM) \quad (2)$$

where I is consumer income, Q_1 is the quantity obtained of the good for which quality information is changing, Q_2 is the quantity of all other goods obtained, P_1 and P_2 are prices of these goods and c is the per unit cost of obtaining product quality information.

With this formulation, one can assume that the cost to the consumer of obtaining information is zero ($c = 0$) if the information is obtained via media coverage of the incident. From the first-order conditions for maximization of the Lagrangean function, the demand for Q_1 is specified as a function of prices, income and information:

$$Q_1 = g(P_1, P_2, I, M) \quad (3)$$

Smith *et al.* develop an approach which is similar to Swartz and Strand in estimating the sales loss following an incident involving heptachlor contamination of fresh fluid milk in Oahu, Hawaii in 1982, except that they also differentiate between positive and negative information following a ban. Positive information released after a ban by public or private agencies, such as a statement that the problem has been eliminated, remaining food supplies are safe, or new safety measures have been undertaken, may have a positive effect on demand. If positive information counteracts the negative effect of a ban on sales, then unnecessary consumer and producer losses which result from imperfect information might be avoided. Swartz and Strand argue that losses would have been avoided in the Baltimore oyster market if the government had provided consumers with better information about the safety of remaining food supplies.

In Smith *et al.*, there are several hypotheses tested regarding model specification for negative and positive media coverage. It is possible that media coverage is primarily negative in the early period of the event when the majority of bans or warnings occur, and that the intensity of negative reporting declines over time. In contrast, positive reporting is expected to increase as contamination diminishes. It is also possible that any news article on contamination has a negative effect on sales, regardless of the positive or negative tone. This hypothesis test implies that any news coverage of the incident would heighten awareness of it, and thus, have a negative effect on sales. Yet another hypothesis is that positive media coverage may not be viewed as credible by consumers. This hypothesis is supported by human information processing studies which suggest that negative information overwhelms positive information in the development of beliefs and attitudes (Weinberger and Dillon, 1980).

In the case of a harvest ban on shellfish products from a particular area contaminated by a toxic algae bloom, a decrease in the demand for the shellfish product may not immediately be the issue, since there will be no impacted shellfish available for purchase. However, past studies of consumer demand in such situations, including Swartz and Strand and Smith, *et al.*, as well as reports in popular press indicate that sales decline as a result of consumer reaction to such incidents, despite adequate uncontaminated supplies. In addition, these incidents affect sales of those producers whose product were contaminated, as well as sales of those producers whose product was not contaminated.

Swartz and Strand hypothesize that perceived quality of uncontaminated food supplies may decline after a ban because consumers have imperfect information about the suspect portion of the product supplies. This has been confirmed in the case of shellfish bans (Shumway, 1990; Conte, 1984; and Nishitani and Chew, 1988). Consumers' primary source of information, media coverage of the incident, may not be sufficiently detailed to enable them to determine which type of shellfish is actually affected, the harvest location of the affected shellfish, and the duration of the effect. Thus, industry-wide demand declines with the extent of negative media coverage of the ban, because this coverage lowers consumer's perceptions of overall product quality (or increases consumers' perceptions of health risks).

Estimated Model

The domoic acid contamination of mussels from PEI in 1987 serves as an example of a toxic algae bloom incident for which the effect on demand, and subsequent sales losses, may be estimated. The models to be estimated test hypotheses regarding the impact of positive versus negative information on demand, as well as the extent to which cumulative information affects demand.

The data used to estimate these models are derived from weekly sales data of Great Eastern Mussel Farms, Incorporated, or Tenants Harbor, Maine, to the Montreal market from May 5, 1987 through March 26, 1991. The focus is on the Montreal market since it is: a) a large market for mussels; b) has easily documented newspaper articles from the Montreal Gazette; c) other economic variables are easily obtained; and d) the location of most of the reported illnesses from this event. Market level data for all mussel suppliers to Montreal is not available. However, Great Eastern Mussel Farms graciously allowed us to use their sales data on the condition that confidentiality of the data is maintained.

Mussels sold by Great Eastern Mussel Farms are shipped to wholesale firms in Montreal. These wholesalers do not contribute any value-added to the product, but rather immediately supply product to retail markets and restaurants. Given that mussels must be sold live in the retail market, it is assumed that a simple mark-up margin is used from the wholesale level to the retail level. Since Great Eastern Mussel Farms is one of many suppliers to the Montreal market, a perfectly competitive environment is assumed.

There is apparent seasonality in the sales of mussels; in particular, sales typically decline in summer months. Based on personal communication with Great Eastern Mussel Farms personnel, seasonality also includes an upswing in demand associated with Christmas and New Year celebrations and the Lenten period. Sales were constrained to zero during a four week period from December 8, 1987 through January 9, 1988, due to the government ban on sales of all Canadian and U.S. Atlantic Coast shellfish.

Demand is hypothesized to be characterized by one of the following single-equation models, where the exclusionary restrictions are tested:

Model I	$Q_m = g(P_m, P_x, X, I, N, P, CN, CP, D1)$	(4)
Model II	$Q_m = g(P_m, P_x, X, I, N, P, D1)$	(5)
Model III	$Q_m = g(P_m, P_x, X, I, N, CN, D1)$	(6)
Model IV	$Q_m = g(P_m, P_x, X, I, N, D1)$	(7)

where Q_m is the number of bushels of mussels demanded from Great Eastern Mussel Farms by wholesalers in Montreal, P_m is the real price of mussels per bushel sold by Great Eastern Mussel Farms to the Montreal market in Canadian dollars, P_x is the real price of other meats and fish in the Montreal market in real Canadian dollars, X is a vector of demand shifters other than income, and I is workers' average weekly income in Quebec in real Canadian dollars.[4] Details regarding explanatory variables are provided in Table 1.

To capture the effects of consumer information, N is the number of negative articles appearing in the *Montreal Gazette* per week, P is the number of positive articles appearing in the *Montreal Gazette* per week, CN is a cumulative variable which is the total number of negative articles appearing in the *Montreal Gazette* during the four prior weeks, similarly, CP is a cumulative variable for positive articles. A four-week cumulative variable was specified because a significant portion of the negative articles appear during the four weeks of the ban on all Atlantic coast mussels (including mussels from Maine). Since there are no sales by Great Eastern Mussel Farms during this four week period, these observations are excluded from the estimation. However, it is reasonable to conclude that the articles which appeared during that four week period may have had an affect on

[4] Weekly wholesale prices of sirloin, chuck, pork loin and chicken in Montreal were obtained from Agriculture Canada; a weekly price index for fresh fish in Quebec was obtained from Statistics Canada. Average weekly income in Quebec was obtained from Statistics Canada. The Canadian consumer price index and U.S./Canada dollar exchange rate were obtained from the International Monetary Fund.

Table 1
Description of the Data

Variable	Units	Mean	Minimum	Maximum
Q_m	weekly sales of mussels (bushels)	—*	—*	—*
P_m	real price mussels (Cdn$/bushel)	—*	—*	—*
I	real income (Cdn$/week)	322.1	304.2	330.4
P_{CH}	real price chicken (Cdn$/kg)	2.0	1.6	2.3
P_{CK}	real price chuck (Cdn$/kg)	2.5	1.7	3.0
P_P	real price pork loin (Cdn$/kg)	3.2	2.6	4.3
P_S	real price sirloin (Cdn$/kg)	4.2	3.8	4.8
P_F	real price index fish	99.8	89.6	106.8
RETAIL	proportion of bushels as bags to total bushels	0.5	0	0.8
N	number of negative articles/week	—	0	5
CN	cumulative number of negative articles/week	—	0	26

* Withheld to preserve confidentiality.

demand for Great Eastern Mussel Farms mussels after the lifting of the ban. It is important to remember that even after bans on U.S. product were lifted in January 1988, bans remained on some Canadian product until the first week of March 1988.

Media coverage of mussels, at times, discussed information not related to the PEI event, but which could potentially have an impact on consumers' demand for mussels. One example is an incident in 1989 in which a man in Montreal died following consumption of mussels at a restaurant. The fact that the mussels were from Great Eastern Mussel Farms was explicitly mentioned. Later it was determined that the man actually died from carbon monoxide poisoning, however, the association of mussels with his death, particularly Great Eastern Mussel Farms mussels, may have impacted demand for the product. The binary variable, D89, was specified to capture the potential impact of this event on demand. The binary variable, D1, differentiates between the ban period on Canadian mussels (January 9, 1988 through March 2, 1988) and the period post March 2. This binary variable is used as both an intercept shifter and a slope shifter in interactive terms with the other information variables.

Questions can be raised regarding how consumers' beliefs or perceptions of risks associated with consuming mussels are altered by the news media. Van Ravenswaay and Hoehn (1991) postulate that the impact of a single article may decline with time or continue over time until an announcement that the hazard is gone. The total amount of information (cumulative number of articles) received may also affect perceived risk. Alternatively, past information may have an effect which diminishes over time. The hypothesized models presented above test for the significance of (1) differentiating between positive and negative media impacts, (2) possible cumulative media impacts, and (3) shifts in demand for Great Eastern mussels during the government ban on only Canadian mussels.

Estimation Results and Discussion

The models discussed above were estimated using ordinary least squares estimation with 198 observations. Results are presented in Tables 2 and 3. Hypothesis tests indicated no significant autocorrelation is present. Models I, III and IV are

Table 2
Regression Results for Model III

Variable	Coefficient	(t-ratio)
P_m	−15.81	(3.35)*
P_{CH}	−133.9	(2.80)*
P_{CK}	165.3	(4.81)*
P_P	22.21	(1.16)
P_S	26.48	(0.76)
P_F	−12.34	(6.75)*
I	2.64	(2.00)*
HOLIDAY	−4.375	(0.22)
LENT	32.21	(1.97)*
SUMMER	−39.06	(2.24)*
D89	−150.4	(2.07)*
RETAIL	129.2	(2.51)*
DOVER	246.9	(6.02)*
DUNDER	−256.92	(6.75)*
N	−30.23	(2.26)*
N1	4.466	(0.13)
CN	−34.15	(3.31)*
CN1	37.12	(3.34)*
D1	−113.8	(3.01)*
CONSTANT	724.9	(1.76)

* Indicates significance at the 95% confidence level; n = 198; R^2(adjusted) = 0.6418; D-W = 1.83; Model II vs. Model I F = 1.865; Model IV vs. Model II F = 0.60; Model I vs. Model III F = 0.831; Model IV vs. Model III F = 2.73.

nested models. Likewise, Models I, II and IV are nested models. F-tests indicate that Models I and IV are rejected in favor of Model III. In addition, F-tests reject models IV and I in favor of Model II. A non-nested test of Models II and III indicates that Model II is rejected in favor of Model III.

The selection of Model III implies that the information gained via the media affected demand both contemporaneously and through a cumulative effect where past information is retained and continues to impact risk perceptions. This result differs from past studies (Swartz and Strand, 1981; van Ravenswaay and Hoehn, 1991; and Smith *et al.* 1988), which have selected a variable for media in the current period plus lagged media variables model or a cumulative total information index model, but not both.[5] Johnson (1988), in an analysis of grain product demand given reports of potential product contamination with ethylene dibromide (EDB), also distinguishes between current and cumulative effects. The cumulative variable is interpreted as indicative of the magnitude or perceived magnitude of the problem.

[5] An alternative specification to the cumulative variable is a lag structure. Use of a set of four-week lagged information variables significantly reduced the statistical fit of the estimated equations.

Table 3
Regression Coefficients (t-ratio) for Models I, II, and IV

Variable	Model I	Model II	Model IV
P_m	−16.43 (−3.53)*	−14.46 (−3.01)*	−13.70 (−2.86)*
P_{CH}	−118.3 (−2.49)*	−140.3 (−2.88)*	−143.3 (−2.93)*
P_{CK}	170.8 (5.05)*	160.8 (4.58)*	161.5 (4.57)*
P_P	24.27 (1.28)	38.14 (2.03)*	37.76 (1.99)*
P_S	30.58 (0.89)	19.67 (0.55)	23.95 (0.67)
P_F	−12.49 (−6.94)*	−14.02 (−7.81)*	−14.03 (−7.77)*
I	2.62 (1.97)*	2.37 (1.76)	2.18 (1.61)
HOLIDAY	−4.30 (−0.22)	2.09 (0.10)	3.25 (0.16)
LENT	34.43 (1.84)	35.75 (1.93)*	34.21 (1.84)
SUMMER	−38.25 (−2.23)*	−39.47 (−2.21)*	−39.34 (−2.19)*
D89	−131.3 (−1.58)	−77.98 (−0.91)	−129.3 (−1.74)
RETAIL	146.0 (2.87)*	126.4 (2.41)*	123.8 (2.35)*
DOVER	252.0 (6.24)*	242.2 (5.78)*	240.3 (5.71)*
DUNDER	−253.9 (−6.79)*	−260.3 (−6.70)*	−261.1 (−6.68)*
N	−32.00 (−2.43)*	−28.71 (−2.10)*	−27.97 (−2.04)*
N1	77.22 (1.62)	15.78 (0.58)	16.65 (0.61)
CN	−35.69 (−3.41)*	—	—
CN1	25.76 (1.99)*	—	—
P	−17.92 (−0.42)	−53.07 (−1.22)	—
P1	114.6 (1.81)	71.14 (1.48)	—
CP	17.49 (1.32)	—	—
CP1	16.04 (0.78)	—	—
D1	−244.00 (−3.36)*	−93.99 (−2.49)*	−76.49 (−2.31)*
CONSTANT	687.9 (1.67)*	932.0 (2.24)*	962.3 (2.30)*

* Indicates significance at the 95% confidence level; n = 198; Model I:R^2(adj) = 0.6203; DW = 1.85; Model II:R^2(adj) = 0.5972; DW = 1.77; Model IV:R^2(adj) = 0.5970; DW = 1.74.

Coefficient Estimates on Economic Variables

All non-information related coefficients are significant at the 95% confidence level, with the exception of coefficients for pork and sirloin prices, the holiday variable, and the constant term. The coefficient on P_m is negative with an own-price elasticity of −1.98 at the means of all variables. Price elastic demand likely reflects the perfectly competitive environment, where wholesalers can relatively easily switch between suppliers. Coefficient signs for prices of other proteins (red meats, chicken, and fish) may be negative or positive. In fact, the results indicate that chicken and fish are complements with mussels, while chuck meat is a substitute; pork and sirloin coefficients are not significantly different from zero. While some collinearity is present, all meat product prices remain in the model because the null hypothesis that the coefficients on these price variables jointly equal zero was rejected using a partial F-test. The estimated coefficient on income is positive and significant, with an income elasticity of 3.56.

Product sold by Great Eastern Mussel Farms includes a one kilogram plastic bag of mussels with their company logo, use by dates, recipes, and guarantees of freshness and quality printed on the bags. Bushels of these bagged mussels go to the retail market while bushels of loose mussels tend to go to the restaurant market. Over time, sales of these bags, as opposed to bushels of loose mussels, have become a larger proportion of sales. To account for this shift in product composition, a variable, RETAIL, is specified which equals the fraction of total bushels sold in retail bag form. The estimated coefficient is positive, indicating that the retail product has had a positive impact on quantity of mussels sold.

A dummy variable, D89, accounts for the week during which Great Eastern Mussel Farms product was erroneously associated with a carbon monoxide poisoning. A negative and significant value indicates that this event did have a substantial impact on product demand. The dummy variables DOVER and DUNDER represent four weeks of accounting discrepancies in which sales were apparently under-reported in one week followed by over-reporting in the next week. These estimated coefficients are of opposite sign and almost equal magnitude, lending support to this assumption.

Coefficient Estimates on Information Variables

The estimation results related to the information variables are largely significant. Interpretation of these results would suggest that negative articles in the *Montreal Gazette* contributed to a decrease in demand. However, this decrease is not significantly different between the period of the ban on some Canadian mussels (January, 9 through March 2) and the period after all bans are lifted (*i.e.*, the coefficient for N1 is not significant). This may be partly explained by re-iterating that Great Eastern Mussel Farms' product may be differentiated from products of other sources, both by the wholesalers who buy the product, and the subsequent consumers who purchase it at retail outlets because of its unique packaging. Consumers may have avoided perceived risk by purchasing or shifting to Great Eastern Mussel Farms' product during the ban period, thereby offsetting the negative effect of the Canadian mussel ban. After all bans were lifted, mussels from other sources, including within Canada, may have been viewed as being equal in value and safety to Great Eastern mussels.

Interestingly, the distinction between the period between January and March 1988 when a ban remained in effect for some Canadian product and the subsequent period when all bans had been removed proves significant for the cumulative effects of information. During the period of the ban, the coefficient on the interactive cumulative variable ($CN1 = D1 * CN$) as well as the net effect of cumulative negative information, is positive. It is possible that the cumulative onslaught of negative information regarding tainted Atlantic Canada mussels may have moved demand toward Great Eastern Mussel Farm product, even though Great Eastern did not initiate any advertising campaigns in that period. Thus, the net effect of cumulative negative information during the January–March period is slightly positive (e.g. $\alpha_0 + \alpha_1$ from $\alpha_0 CN + \alpha_1(D1 * CN)$). However, cumulative negative information which occurs post-algae contamination does have a large negative effect.

These results suggest that, during the ban period, consumers are basing their demand decisions primarily on immediate news (e.g. bans and government monitoring) rather than on past news. In contrast to past studies where research addresses perceived chronic health hazards involving chemicals (*e.g.*, alar, kepone, heptachlor) with potential health effects not measurable during the periods of study, this study addresses perceptions of immediate or acute health hazards. The nature of these perceived risks may determine how consumers respond to negative information regarding the incident. In the case of domoic acid, consumer deaths were attributed to the incident, implying a much more acute health hazard. Under acute hazard scenarios, the impact of new or current period information may have a large effect on demand, while cumulative effects are less significant. Confidence in government monitoring programs may provide sufficient assurance that non-persistant toxins such as domoic acid will not be a source of acute risk.

Shifts in demand associated with product contaminated by more persistent toxic contaminants such as some pesticides or chlorinated waste compounds (*e.g.*, chemicals capable of accumulating over time in the tissues of marine organisms or other harvested products) may exhibit the information effects opposite to those of acute hazards. The demand impact of total cumulative information about products containing persistent compounds, with suspected symptoms not observable until extended periods after exposure, may be greater than is the case with contaminants exhibiting acute effects. Current information regarding an acute toxin is likely to discuss recent concentrations measured by monitoring programs, potential bans on products, or other immediate action; current information regarding chronic toxins is more likely to discuss on-going monitoring program results or updates on research information.

Brown and Schrader (1990), in an assessment of the impacts of cholesterol information on egg consumption, found significant negative coefficients for cumulative article variables, and confirmed the hypothesis that the effect of news articles declines as information accumulates. These results appear to conform to a hypothesized pattern of gradual development in risk perception associated with cumulative information regarding chronic health effects (which cholesterol can be assumed to exhibit). It is expected that the effect of articles regarding chemicals inducing acute health impacts would have a greater impact on the immediate period with cumulative impacts declining faster over time, relative to chronic hazards. Additional research may be needed to distinguish between the information effects associated with the two health hazard types.

Sales Losses

Sales losses incurred by Great Eastern Mussel Farms during the domoic acid contamination of PEI mussels in 1987 can be calculated using the estimated demand equation discussed above. Losses incurred by Great Eastern Mussel Farms is not necessarily reflective of the total sales loss to the mussel industry because: (1) Great Eastern Mussel Farms is only one of several U.S. producers supplying the Canadian market; (2) there are many Canadian producers which were also affected; and (3) the focus of the sales losses has been on the Montreal market, which is only a portion of the total market supplied by Great Eastern Mussel Farms and other mussel producers. However, estimated sales losses for Great Eastern Mussel Farms is an appropriate indicator of the potential magnitude of sales losses to the mussel industry due to this event.

The sales loss is assumed to be composed of two parts. First, there is the obvious loss which is incurred during the four week ban on all mussel sales, including U.S. mussels, to the Canadian market from December 8 through January 8. Out-of-sample forecasts using the estimated model, with all of the information variables set to zero provides predicted quantities sold, had there been no domoic acid contamination event. Multiplying that quantity loss by prices which would have been received (using prices charged to U.S. wholesalers as a proxy) results in total sales losses for this period. These losses are equivalent to approximately 8% of Great Eastern Mussel Farms average annual sales to Montreal during 1989–1990.[6] Second, it is possible that sales losses also were incurred by the firm following the lifting of the ban on U.S. product, when the media coverage continued to inform consumers of the contamination event. This information continued until March 2, when the last of the bans on mussel consumption was lifted. Thus, sales losses for the period from January 8, 1988 through March 2, 1988, while some Canadian product remained banned and reports continued to surface regarding the event, may be calculated by taking the difference between predicted values without an event (i.e. no information related variables) and predicted values of the full model.[7] These losses are approximately 6.5% of Great Eastern Mussel Farms' average annual sales to Montreal during 1989–90. Combined, sales losses for Great Eastern Mussel Farms during the height of the domoic acid event, December 8, 1987 through March 2, 1988, amounts to approximately 14.5% of its average annual sales during 1989 and 1990.

Although the contamination event occurred during the holiday season when demand is traditionally high, these losses may in fact be less than they could have been for Great Eastern Mussel Farms. In particular, consumers were provided with information that U.S. mussels were uncontaminated as of January 8, 1988. Since a large proportion of product sold by this firm is sold in the one kilogram bags clearly labeled with origin (Maine) and guarantees of quality and freshness, it is possible that consumers may have switched from purchasing unbranded loose mussels, perceived as a higher health risk, to Great Eastern mussels. Thus, while demand dropped following the contamination event, the decrease in demand for Great Eastern Mussel Farms product may have been less than for those producers whose product is unlabeled.

As stated earlier, sales losses to one U.S. firm due to the toxic algae contamination does not provide information on the full extent of economic losses to the mussel industry due to a decrease in demand. This analysis has focused on only one firm, and only sales to Montreal. It is likely that there were lost sales in the rest of Canada, particularly Atlantic Canada, as well. However, it does indicate that sales losses were significant, and that these sales losses were likely near the lower bound of potential losses because Great Eastern Mussel Farms had several advantages over other producers. First, they benefited from being U.S. producers, thus the ban on their product was relatively short-lived. Second, their product was clearly labeled as U.S. product which may have relieved the risk perceptions of consumers. Thus, producers in Canada, particularly in PEI, are more likely to have faced significantly higher sales losses.

[6] Actual dollar amounts are not given to preserve confidentiality.
[7] Estimated actual sales were used rather than observed values to minimize errors in sales loss estimates. Since estimated actual sales are used, the standard error equals the standard error of projected sales given no contamination minus the standard error of estimated actual sales. This difference is the error due only to the information variables (Smith *et al.* (1988)).

Conclusions and Summary

This paper illustrates the importance of toxic algae bloom contamination for fisheries and the seafood industry. A possible theoretical approach to incorporating consumers' responses to these contaminations into consumer demand models was discussed, and an empirical case study was provided of sales losses from the domoic acid contamination of mussels from Prince Edward Island on a firm outside Canada whose product was unaffected by the contamination. Based on the methodology used, where consumer information regarding product quality was assumed to be a function of the number of newspaper articles, the sales losses to this firm were calculated. While the results did not indicate large losses in sales for this firm, there was a reduction in demand following the algae contamination. Further research will investigate the robustness of these results when alternative functional forms, which do not rely on the relatively subjective measures of newspaper articles, are estimated.

There are several reasons why it is important to quantify the economic losses to the fishing industry which result from a decrease in demand due to toxic algae blooms and subsequent bans on sales of affected shellfish. Perhaps most obvious is that industry benefits from a better understanding of the impacts of perceived product quality on consumer demand for their product. Quantifying sales losses is also important for several public policy reasons. Toxic algae blooms are believed to originate primarily in the ocean, as opposed to bays or inshore areas, and bloom development can be very rapid, leaving little time for fishery management precautions (Shumway, 1990). Given the variety of complicating factors controlling red tide occurrence, there is still a great deal of uncertainty in predicting blooms. However, advances in the science of algae blooms and their determinants will eventually reduce the uncertainty associated with predicting these events. Thus, fishery management policies and information/contingency plans could be adapted to take into account the probability of an event occurring and the timing of the events to minimize the economic loss to the fishery.

At both the state and national level, provision of accurate information regarding toxic algae bloom contamination of shellfish supplies is necessary to maximize consumer welfare. In the states most affected by toxic algae blooms, programs have been initiated which provide public education about these events. Some of these programs are very modest in nature, while others, such as the programs in the Canadian maritime provinces, are broad in scope and aggressive. These programs are in place, for the most part, to protect the public health and do so by posting notices at closed shellfish beds to discourage recreational harvest and through public announcements of these closures (Nishitani and Chew, 1988). The benefits of such public information programs accrue to both consumers and industry.

From a public environmental policy perspective, governments may consider policies with the stated objective of reducing the number and size of occurrences of toxic algae blooms through, for example, coastal pollution reduction programs. In evaluating such programs, policy makers must take into account the potential costs of such a program, as well as the potential benefits. Among the benefits of reduced algae blooms is the reduction or elimination of sales losses incurred by the industry as a result of consumer perception of unsafe product in addition to reduced health risk.

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