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Assessing the Economic Consequences of Harmful Algal Blooms: A Summary of Existing Literature, Research Methods, Data, and Information Gaps

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8.1 Introduction

Harmful algal blooms (HAB) are marine or freshwater natural hazards that can lead to serious public health and socioeconomic consequences, depending upon their spatial distributions relative to: (1) human populations, (2) durations and frequencies of occurrence, (3) cell densities and toxicities, and (4) weather conditions. The focus of this chapter is mainly on the economic consequences of *marine* HAB. Several reports and studies have characterized the types and magnitudes of the adverse economic effects associated with marine HAB in the United States (Adams *et al*., 2000, 2002; Anderson *et al*., 2000; Hoagland *et al*., 2002; Hoagland and Scatasta, 2006; Hoagland, 2008; Ralston *et al*., 2011; Adams and Larkin, 2013). While the economic effects of marine HAB have received significant attention in the past, the economic effects of *freshwater* HAB now also are being assessed (Dodds *et al*., 2009; Bingham *et al*., 2015). Further evaluations of the impacts of HAB on the human uses of and values for both marine and freshwater resources could justify expanded public investments in natural and social scientific research, thereby supporting decisions to identify and implement appropriate prevention, mitigation, or control strategies.

Informed enquiry into the relevant economic methodologies, necessary data, and gaps in current understanding would help to delineate a national program of socioeconomic research, further clarifying the nature of the hazards and thereby guiding future scientific research efforts. In the United States, several science funding programs at the federal level could benefit from such guidance, including the interagency program on Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) and the NOAA programs on Monitoring and Event Response for Harmful Algal Blooms (MERHAB) and Prevention, Control, and Mitigation of Harmful Algal Blooms (PCMHAB). The actions of state and municipal agencies to manage coastal and marine resources, especially shellfisheries, and to protect the public health also would likely benefit.

This chapter summarizes an extant literature that seeks to evaluate many of the economic consequences associated with marine HAB. The discussion utilizes a report by Adams and Larkin (2013) containing an annotated bibliography of both peer-reviewed and "gray" (no formal peer review) research papers. That bibliography is supplemented with publications from the more recent literature, focusing on the peer-reviewed literature and adding examples from the methodologically rigorous gray literature. Specifically, this chapter discusses methodologies that have been used to measure economic losses, review the types and sources of data, depict the spatial distribution of examples where economic impacts have been estimated in the United States, discuss the complexities of addressing the scopes of HAB events, and identify research gaps and areas for focusing future socioeconomic research efforts.

Harmful Algal Blooms: A Compendium Desk Reference, First Edition. Edited by Sandra E. Shumway, JoAnn M. Burkholder, and Steve L. Morton.

8.2 Overview

The following discussion summarizes 36 studies that estimated the economic losses of single or multiple HAB events over time. The summary is organized according to four criteria: (1) the methodologies used to assess the economic effects, (2) the sources and types of data, (3) the spatial or temporal scopes of the analyses (e.g., the accounting stances or time steps), and (4) the physical characteristics of the relevant hazard (e.g., the species and the harmful effects that are being measured). Each criterion is discussed with respect to the full collection of studies. Note that some overlaps among the criteria exist (e.g., methodologies and data often are logically linked). The individual studies are summarized and annotated briefly in Table 8.1.

8.3 Research Methodologies

The most basic distinction regarding approaches used to estimate economic consequences is whether the consequences are "market" or "non-market." Market-related losses are those that can be calculated from changes in prices or quantities of goods or services (as a result of a HAB) that are physically traded; market losses can be used to identify the tangible effects of HAB with data from either direct or surrogate markets. Non-market goods comprise those for which no formal market exists, and thus a theoretical equilibrium price and quantity cannot be observed. Non-market losses could relate to the adverse effects of HAB on recreational uses of coastal or ocean resources, such as sportfishing or beachgoing, or on passive uses, such as perceptions of well-being associated with healthy ecosystems.

In applying market-based methods, it is important to characterize the distribution of effects across producers (private firms or individuals), consumers, or both. *Direct market methods* are those that use data that reflect a change in market value, revenues, or expenditures, such as lost seafood market sales, lost reported sales by water-proximate businesses, or the costs of HAB monitoring or cleanup. *Surrogate market methods* use data from related or substitute markets to capture a change in value, such as depressed real estate values or the increased costs of travel to substitute recreational sites.

Ideally, using market data, one would want to develop models of supply and demand in the relevant product or service markets, and thereby calculate losses of economic surpluses to both producers and consumers when HAB negatively influence the use of coastal or ocean resources (Figure 8.1). Kahn and Rockel (1988) provide one of the few such analyses with respect to harmful blooms of the brown tide *Aureococcus anophagefferens*, which have led to the complete loss of the bay scallop *Argopecten irradians* fishery in the Peconic Estuary of Long Island, New York. Only rarely are such studies undertaken, however, because of data deficiencies or the expenses of undertaking the analyses.

Measuring losses to *producers* using direct market data is one of the most common – albeit often flawed in its application – methods of evaluating economic effects. In spite of its flaws, this approach is relatively easy to implement, and it has been adopted for use by policy makers in assessing the need for relief to producers affected adversely by HAB "disasters." Figure 8.2 and Table 8.2 depict the spatial distribution and scale of several examples of marine HAB for which economic impacts have been estimated. Typically, an estimate is made of reduced or lost output from a market, such as a seafood market, multiplied by a price for the lost output. Such estimates are known as lost gross revenues or *direct output impacts* (DOIs). Where a regional economic (input–output, or IO) model exists, indirect and induced impacts also can be evaluated by adjusting the estimate of DOIs with a "multiplier" (cf. Shumway *et al.*, 1988, for reference to such an application during HAB-related shellfish closures in Maine). *Indirect impacts* are changes in output in industry sectors that are linked to a sector experiencing DOIs, such as changes in the output of upstream suppliers as a consequence of reductions in shellfish digging and growing during a HAB. *Induced impacts* are changes in spending by workers in the affected direct and indirect sectors. In practice, the DOI approach has been used to determine the level of fishery disaster relief claims made pursuant to §312 (a) of the federal Sustainable Fisheries Act (P.L. 104-297). For example, the direct, indirect, and induced output impacts of shellfish closures in New England resulting from widespread blooms of *Alexandrium fundyense*, a HAB that can cause paralytic shellfish poisoning (PSP) in humans, were evaluated by state officials in Maine, New Hampshire, and Massachusetts to substantiate successful disaster relief claims in 2005 and 2008.

From the perspective of welfare economics, however, estimates of DOIs do not match true economic losses, and, without careful modeling of

Table 8.1 Summary of research evaluating the economic consequences of HAB or related events.

Authors	Agundez *et al.*	Athearn	Chadsey *et al.*	Diaby	Cummins
Title	Technical Adoption to Harmful Algal Blooms: Socioeconomic Consequences for the Shellfish Farming Sector in Bourgneuf Bay (France)	Economic Losses from Closure of Shellfish Harvesting Areas in Maine	Cooperation of Science and Management for Harmful Algal Blooms: Domoic Acid and the Washington Coast Razor Clam Fishery	Economic Impact of Neuse River Closure on Commercial Fishing	Potential Economic Loss to the Calhoun County Oystermen
Publisher (and type of publication)	*Aquaculture Economics & Management* (journal)	University of Maine (working paper)	*Coastal Management* (journal)	North Carolina Division of Marine Fisheries (agency report)	Dolphin Talk (online publication)
Year published	2013	2008	2012	1996	2012
Temporal scope	1997–2007	2001–2005	2005–2008	1995	2011–2012
Spatial scope	Bourgneuf Bay area (Pays de la Loire region, France)	Maine	Coast of Washington State	Neuse River, North Carolina	Calhoun County, Texas
Method	DOI: Estimated economic performance, cost of new technology, and economic viability	DOI: Estimated decline in landings, input–output modeling (IMPLAN)	RP: Institutional analysis and development (IAD) framework	DOI: Calculation of reduction in landings from previous year	DOI: Calculated decline in dockside value
Source or type of data	Survey of industry; small-scale fishery management (primary/secondary)	Maine Department of Marine Resources (secondary)	Survey of experts; other papers (primary/secondary)	Surveys of seafood dealers; North Carolina Division of Marine Fisheries (primary/secondary)	Texas Parks and Wildlife Department (secondary)
Algae or toxin	*Pseudo-nitzschia, Alexandrium*	*Alexandrium fundyense*/PSP	*Pseudo-nitzschia*	*Pfiesteria* spp.	*Karenia brevis*

Authors	Dodds *et al.*	Dyson and Huppert	Evans and Jones	Habas and Gilbert	Hoagland *et al.*
Title	Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages	Regional Economic Impacts of Razor Clam Beach Closures due to (HAB) on the Pacific Coast of Washington	Economic Impact of the 2000 Red Tide on Galveston County, Texas: A Case Study	The Economic Effects of the 1971 Florida Red Tide and the Damage It Presages for Future Occurrences	The Economics Estimates of HAB in the U.S.: Estimates, Assessment Issues and Information Needs
Publisher	*Environmental Science & Technology* (journal)	*Harmful Algae* (journal)	Texas A&M University (agency report)	*Environmental Letters* (journal)	*Estuaries* (journal)
Year published	2008	2010	2001	1974	2002
Temporal scope	Unspecified	April 2008	2000 Red tide event	1971	1987–1992
Spatial scope	U.S. freshwaters	Washington State (Pacific and Grays Harbor counties)	Galveston County, Texas	Southwest Florida	United States

(*continued*)

Table 8.1 (*Continued*)

Authors	Dodds *et al.*	Dyson and Huppert	Evans and Jones	Habas and Gilbert	Hoagland *et al.*
Method	DOI: Calculated reductions multiplied by value	DOI: Input–output analysis (IMPLAN)	DOI: Input–output analysis (IMPLAN)	RP: Calculation of losses to tourism industry and commercial fishermen	DOI, RP: Calculation of losses per event, averaged annually
Source or type of data	Unspecified (secondary)	Survey of recreational clammers (primary)	Survey of agencies; Texas Parks and Wildlife; Texas Department of Health (primary/secondary)	Survey of industry; Florida Department of Revenue; accountant records (primary/secondary)	Survey of experts; literature review (primary/metadata)
Algae or toxin	*Cyanobacteria/Microcystins*	*Pseudo-nitzschia, Alexandrium*	*Karenia brevis*	*Karenia brevis*	Multiple species and toxins

Authors	Hoagland *et al.*	Hoagland *et al.*	Jin and Hoagland	Jin *et al.*	Kahn and Rockel
Title	The Human Health Effects of Florida Red Tides: An Expanded Analysis	The Costs of Respiratory Illnesses Arising from Florida Gulf Coast *Karenia brevis* Blooms	The Value of HAB Predictions to the Nearshore Commercial Shellfish Fishery in the Gulf of Maine	Economic Impact of the 2005 Red Tide Event on Commercial Shellfish Industries in New England	Measuring the Economic Effects of Brown Tides
Publisher	*Environment International* (journal)	*Environmental Health Perspectives* (journal)	*Harmful Algae* (journal)	*Ocean and Coastal Management* (journal)	*Journal of Shellfish Research* (journal)
Year published	2014	2009	2008	2008	1988
Temporal scope	1999–2009	2001–2006	Event specific	1990–2005	Unspecified
Spatial scope	Southwest Florida	Sarasota County, Florida	New England (Maine and Massachusetts)	New England (Maine and Massachusetts)	New York State
Method	DOI: Regression model that expresses hospital/ER admissions as a function of red tide events	DOI: Cost estimation: estimated number of cases multiplied by calculated cost of illness	DOI: Calculated value of using HAB prediction model	DOI: Estimated reduction in landings, imports, and prices with values extrapolated	RP: Regression analysis of bay scallop industry
Source or type of data	Florida Agency for Health Care Administration; STR SHARE tourism data (secondary)	Sarasota Memorial Hospital; Mote Marine Lab; CDC; Florida Agency for Health Care Administration (secondary)	NMFS; Massachusetts Division of Marine Fisheries (secondary)	NMFS; U.S. Census Bureau; New York Fulton Fish Market (secondary)	Unspecified
Algae or toxin	*Karenia brevis*	*Karenia brevis*	*Alexandrium fundyense*/PSP	*Alexandrium fundyense*/PSP	*Aureococcus anophagefferens*

Authors	Kirkpatrick *et al.*	Lankia and Huhtala	Larkin and Adams	Lipton	Lucas
Title	Florida Red Tide Knowledge and Risk Perception: Is There a Need for Tailored Messaging?	Valuation of Trips to Second Homes in the Country: Do Environmental Attributes Matter?	HAB and Coastal Business: Economic Consequences in Florida	*Pfiesteria*'s Economic Impact on Seafood Industry Sales and Recreational Fishing	Willingness-to-Pay for Red Tide Prevention, Control and Mitigation Strategies: A Case Study of Coastal Residents

Publisher	*Harmful Algae* (journal)	EAAE 2011 Congress (conference paper)	*Society and Natural Resources* (journal)	University of Maryland (working paper)	University of Florida (MS thesis)
Year published	2014	2011	2007	1998	2010
Temporal scope	2012	Jan 2009	1995 to 1999	January–December 1997	2009
Spatial scope	Sarasota, Florida	Finland	Northwest Florida	Maryland	Florida
Method	SP: Identify knowledge and perceptions of residents and need for tailored outreach efforts	RP/SP: Estimated decline in trips, reduction in CS/trip	RP: Estimated reduction in reported monthly earnings for tourism businesses	RP: Calculation of lost sales and recreational trips (multiplied by $/trip from Strand)	SP: Estimated preference for proposed strategy, WTP
Source or type of data	Survey of residents; other papers (primary/metadata)	Survey of owners of second homes (primary)	Florida Department of Revenue; National Climatic Data Center; Florida Marine Research Institute (secondary)	Survey of seafood industry members; NMFS/MRFSS (primary/secondary)	Survey of coastal residents (primary)
Algae or toxin	*Karenia brevis*	Unspecified	*Karenia brevis*	*Pfiesteria* spp.	*Karenia brevis*

Authors	**Morgan *et al.***	**Morgan *et al.***	**Morgan *et al.***	**Morgan *et al.***	**Nierenberg *et al.***
Title	Empirical Analysis of Media versus Environmental Impact of Park Attendance	Red Tides and Participation in Marine-Based Activities: Estimating the Response of Southwest Florida Residents	Firm-Level Economic Effects of HABS: A Tool for Business Loss Assessment	Public Costs of Florida Red Tides: A Survey of Coastal Managers	Changes in Work Habits of Lifeguards in Relation to Florida Red Tide
Publisher	*Tourism Management* (journal)	*Harmful Algae* (journal)	*Harmful Algae* (journal)	University of Florida (university extension)	*Harmful Algae* (journal)
Year published	2011	2010	2009	2008	2010
Temporal scope	2002–2004	January 2008–December 2008	1998–2005	2004–2007	2004, 2005
Spatial scope	Florida Gulf Coast	Sarasota and Manatee Counties, Florida	Southwest Florida	Florida Gulf coast	Sarasota County, Florida
Method	RP: Estimated the environmental impact of park attendance	RP: Estimated probability of behavioral change by activity	DOI/RP: Estimated reduction in daily restaurant revenues multiplied by affected days	RP: Calculated costs to cities and counties associated with HAB	RP: Test of reduced attendance multiplied by salary
Source or type of data	National Oceanic and Atmospheric Administration (NOAA); other papers (secondary and metadata)	Survey of county residents (primary)	Proprietary business data; National Climatic Data Center (primary)	Survey of coastal managers (primary)	Survey of lifeguards (primary)

(*continued*)

Table 8.1 (*Continued*)

Authors	Morgan *et al.*	Morgan *et al.*	Morgan *et al.*	Morgan *et al.*	Nierenberg *et al.*
Algae or toxin	*Karenia brevis*	*Karenia brevis*	*Karenia brevis*	*Karenia brevis*	*Karenia brevis*

Authors	Nunes and van den Bergh	Oh and Ditton	Parsons *et al.*	Ralston *et al.*	Rodriguez *et al.*
Title	Can People Value Protection against Invasive Marine Species? Evidence from a Joint TC-CV Survey in the Netherlands	A Time Series Approach to Estimating the Economic Impacts of Exogenous Events on Recreational Fishing	The Welfare Effects of *Pfiesteria*-Related Fish Kills in Seafood Markets: A Contingent Behavior Analysis	An Estimate of the Cost of Acute Health Effects from Food- and Water-Borne Marine Pathogens and Toxins in the U.S.	Are Red Tides Affecting Economically the Commercialization of the Galician (NW Spain) Mussel Farming?
Publisher	*Environmental and Resource Economics* (journal)	*Human Dimensions of Wildlife* (journal)	*Agricultural and Resource Economic Review* (journal)	*Journal of Water and Health* (journal)	*Marine Policy* (journal)
Year published	2004	2008	2006	2011	2011
Temporal scope	2001	2001–2003	2001	Annual	1990–2008
Spatial scope	Holland	Possum Kingdom Lake, Texas	Mid-Atlantic region, United States	U.S.	NW Spain
Method	RP/SP: Estimation of recreation demand and travel cost, comparison of WTP	DOI: Estimated reduction in visitors and IMPLAN	SP: Estimated demand functions and CS	DOI/RP: Estimated annual cost from lit review	RP: Correlation between industry metrics and HAB incidence
Source or type of data	Survey of beach visitors (primary)	Texas Comptroller of Public Accounts; Possum Kingdom Lake State Park (secondary)	Survey of seafood consumers (primary)	Other papers (secondary and metadata)	Official agency data (secondary)
Algae or toxin	Unspecified	*Prymnesium parvum*	*Pfiesteria* spp.	Multiple species, toxins	*Alexandrium* spp./PSP

Authors	Rongo and Woesik	Taylor and Longo	Todd	van Beukering and Cesar
Title	Socioeconomic Consequences of Ciguatera Poisoning in Rarotonga, Southern Cook Islands	Valuing Algal Blooms in the Black Sea Coast of Bulgaria: A Choice Experiments Approach	Estimated Costs of Paralytic Shellfish, Diarrhetic Shellfish and Ciguatera Poisoning in Canada	Ecological Economic Modeling of Coral Reefs: Evaluating Tourist Overuse at Hanauma Bay and Algae Blooms at the Kihei Coast, Hawaii
Publisher	*Harmful Algae* (journal)	*Environmental Management* (journal)	Book chapter	*Pacific Science* (journal)

Year published	2012	2010	1995	2004
Temporal scope	1989–2011	1983–2002	Unspecified	2001
Spatial scope	Cook Islands	Black Sea coast, Bulgaria	Canada	Hawaii
Method	SP: Extrapolation of health cost and consumption estimates	SP: Conjoint choice experiment and conditional logit model	DOI/RP: Estimates of # illness multiplied by cost of illness (society and individual, except pain and suffering)	RP: Calculated reductions in business using available dynamic econ-ecological simulation model and available economic values
Source or type of data	Survey of residents (primary and secondary)	Unspecified (primary)	Unspecified (secondary)	Previous studies including survey-based non-market valuation (metadata)
Algae or toxin	CFP	Various species, such as *Skeletonema*, *Cerataulina*, *Prorocentrum*, and *Gymnodinium*	Shellfish poisoning (paralytic, diarrhetic, and ciguatera)	Not specified

Authors	**Wessells *et al.***	**Whitehead *et al.***
Title	Toxic Algae Contamination and Demand for Shellfish: A Case Study of Demand for Mussels in Montreal	The Economic Effects of *Pfiesteria*
Publisher	*Marine Resource Economics* (journal)	*Ocean and Coastal Management* (journal)
Year published	1995	2003
Temporal scope	May 1987–March 1991	2001
Spatial scope	Montreal, Canada; Maine	Delaware, Maryland, North Carolina, Virginia
Method	DOI/RP: Estimation of shellfish demand and sales losses due to information	SP: Estimation of risk perceptions, seafood demand, and WTP for a safety program from CVM study
Source or type of data	Proprietary (weekly sales from one farm and one wholesaler); news articles from the *Montreal Gazette*; Agriculture Canada, Statistics Canada, and IMF for prices and income (primary/secondary)	Survey of seafood consumers (primary)
Algae or toxin	Domoic acid	*Pfiesteria*

Source: Adams and Larkin (2013). CDC, U.S. Centers for Disease Control and Prevention; CVM, contingent valuation method; DOI, direct output impacts; ER, emergency room; HAB, harmful algal bloom; MRFSS, Marine Recreational Fishing Statistical Survey; NMFS, National Marine Fisheries Service; RP, revealed preference; SP, stated preference; WTP, willingness-to-pay.

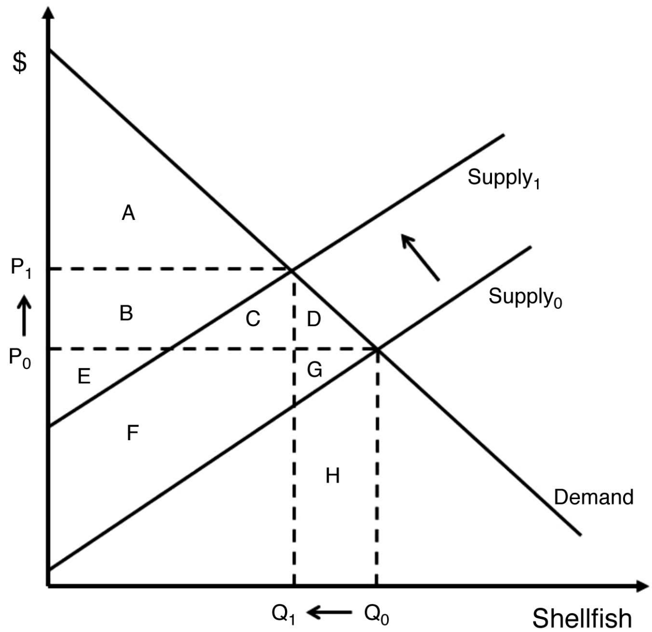

Figure 8.1 Economic welfare effects (value changes) from a hypothetical HAB leading to the closure of shellfish beds. The supply curve shifts in, causing output to the market from shellfish diggers and growers to decline from Q_0 to Q_1 (horizontal axis). Price rises from P_0 to P_1. Direct output impacts (DOIs) typically are calculated as the product of the reduction in output ($Q_0 - Q_1$) and P_0: the sum of areas G + H, where G is a producer surplus and H represents costs. True economic losses comprise changes in consumer and producer surpluses: the sum of areas C + D + F + G. The scale of DOI or value changes will depend upon the amount of shellfish output decline and the slopes of supply and demand in the shellfish market. There might also be changes in welfare associated with a contraction in demand (a *halo effect*), if consumers switch away from shellfish to other seafoods or other foods.

the relevant market, the relationship between the two measures of economic effects can be indeterminate (Figure 8.1). The reason for this is that DOIs comprise both producer surpluses (loosely, business "profits") and the costs of supply. When shellfisheries are closed, for example, diggers or growers relinquish producer surpluses – a true economic loss – but do not incur the costs of digging or growing, and therefore there are no losses associated with the latter. The use of IO multipliers would further compound these overstated losses in upstream supplier markets. Conversely, DOIs could understate economic losses in that they do not account for lost surpluses to consumers. Without an explicit model of the relevant market, it is not feasible to characterize the degree of over- or understating of economic value changes.

A further issue concerns the flexibility that individuals and firms have to avoid the adverse effects of marine HAB. For example, tourists may frequent other restaurants or hotels, fishermen may switch to other fisheries or other sources of employment, and beachgoers might choose to go to another beach (Lucas, 2010). In general, it is sensible to assume that there is an economic loss to producers or consumers when they switch from their preferred activities to alternatives, but the scale of such losses depends upon the availability of alternatives and the ease of switching. If the costs of switching are low, other sectors of the economy could benefit, thereby mitigating the economic impacts of the sectors that are directly affected by a bloom. There are few studies that measure such countervailing impacts. One example concerned the pecuniary effects of price increases in the New York Fulton Fish Market during a large-scale *Alexandrium* bloom restricting softshell clam *Mya arenaria* production in, and supply from, the Gulf of Maine in 2005 (Jin *et al.*, 2008). In the beginning of the bloom, consumers could still find softshell clams, albeit at higher prices. Prices declined as the bloom wore on, suggesting that consumers switched to other seafood or that supply to the market expanded from producers from regions that were unaffected by the bloom.

Notwithstanding this issue, the use of a regional economic impact framework to estimate DOIs and multipliers can give decision makers an

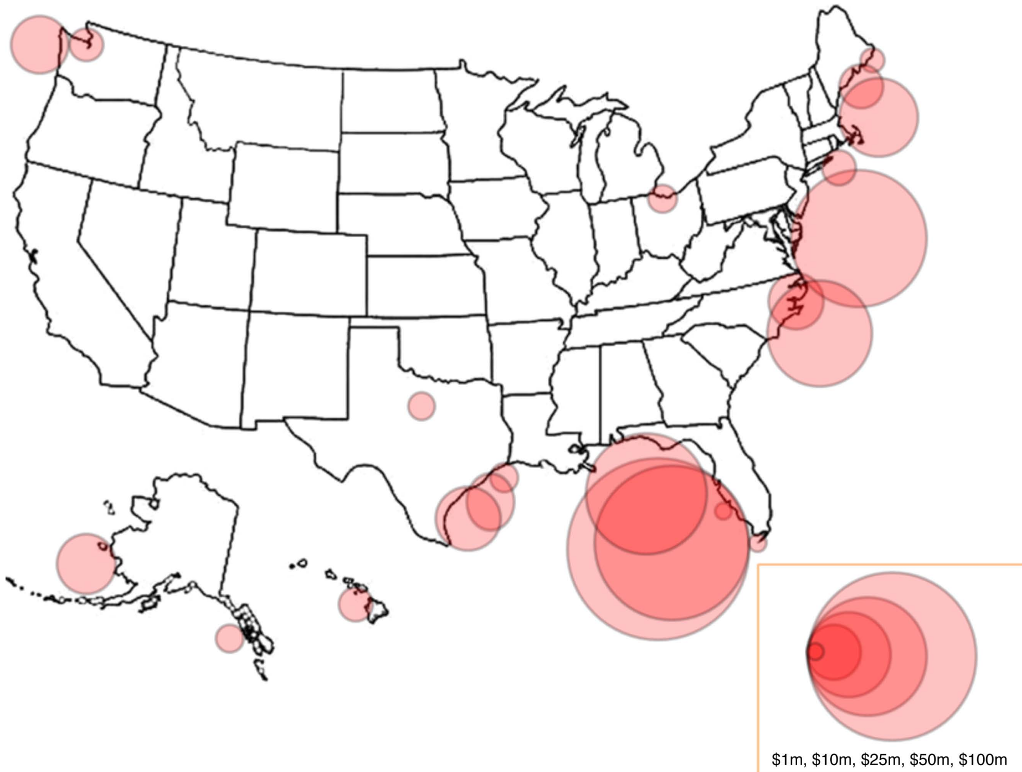

Figure 8.2 Some selected historical examples of HAB in the United States for which economic impacts (2015 dollars, in millions) have been estimated, showing the large range in scales of potential economic impacts. The circles comprise estimates of economic (not spatial) scales at different points in time, beginning in the 1970s; they have been constructed so that their areas are proportional to estimated economic impacts. The maps of Alaska and Hawaii are not drawn to scale. (Refer to the list in Table 8.2 for more detail on the scales and natures of impacts and the sources of the estimates.)

understanding of changes in the distribution of economic activity throughout an economy. For example, Dyson and Huppert (2011) employed an IO model to estimate changes in local income and employment from HAB closures of recreational Pacific razor clam *Siliqua patula* harvests at six beaches in two Washington State coastal counties, finding that a yearlong closure could lead to reduced local incomes of nearly $11 million with a loss of about 340 local jobs.

Measuring losses to *consumers* with either direct or surrogate market data is referred to as a *revealed preference* approach. Revealed preferences rely upon economic values that may be obtained, or revealed, through market data, such as through observations of consumer expenditures. These consumers could be restaurant patrons or recreational boaters, for example. Such market information can be obtained directly from businesses or from surveys that ask recreationists how their behavior changed during a HAB event. As one illustration, using a time-series approach, Larkin and Adams (2007) found that average monthly lodging and restaurant revenues declined by approximately one-third (losses of $3–4 million per month) during months in which Florida red tides (blooms of *Karenia brevis*) occurred in two northwest Florida coastal communities. Likewise, Morgan *et al.* (2009) found that daily sales declined at beachfront restaurants during a Florida red tide. The advantage of using revealed preference data is that such data reflect actual choices that users have made in response to the event.

Unfortunately, for some purposes, such as estimating the value of proposed programs designed to mitigate and control for the effects of HAB, revealed preference data may be unavailable. In those cases, "stated" preference approaches must be used. In contrast to revealed preference approaches, *stated preference* approaches ask individuals, through survey methods, to state their willingness-to-pay for certain goods or services. Survey questions might focus on attenuations in willingness-to-pay for visits to beaches where HAB

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Authors	Agundez *et al.*	Athearn	Chadsey *et al.*	Diaby	Cummins
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Publisher (and type of publication)	*Aquaculture Economics & Management* (journal)	University of Maine (working paper)	*Coastal Management* (journal)	North Carolina Division of Marine Fisheries (agency report)	Dolphin Talk (online publication)
Year published	2013	2008	2012	1996	2012
Temporal scope	1997–2007	2001–2005	2005–2008	1995	2011–2012
Spatial scope	Bourgneuf Bay area (Pays de la Loire region, France)	Maine	Coast of Washington State	Neuse River, North Carolina	Calhoun County, Texas
Method	DOI: Estimated economic performance, cost of new technology, and economic viability	DOI: Estimated decline in landings, input–output modeling (IMPLAN)	RP: Institutional analysis and development (IAD) framework	DOI: Calculation of reduction in landings from previous year	DOI: Calculated decline in dockside value
Source or type of data	Survey of industry; small-scale fishery management (primary/secondary)	Maine Department of Marine Resources (secondary)	Survey of experts; other papers (primary/secondary)	Surveys of seafood dealers; North Carolina Division of Marine Fisheries (primary/secondary)	Texas Parks and Wildlife Department (secondary)
Algae or toxin	*Pseudo-nitzschia, Alexandrium*	*Alexandrium fundyense*/PSP	*Pseudo-nitzschia*	*Pfiesteria* spp.	*Karenia brevis*

Authors	Dodds *et al.*	Dyson and Huppert	Evans and Jones	Habas and Gilbert	Hoagland *et al.*
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Publisher	*Environmental Science & Technology* (journal)	*Harmful Algae* (journal)	Texas A&M University (agency report)	*Environmental Letters* (journal)	*Estuaries* (journal)
Year published	2008	2010	2001	1974	2002
Temporal scope	Unspecified	April 2008	2000 Red tide event	1971	1987–1992
Spatial scope	U.S. freshwaters	Washington State (Pacific and Grays Harbor counties)	Galveston County, Texas	Southwest Florida	United States

(*continued*)

occur, for example. Stated preference approaches also could ask respondents how they would vote on a referendum to establish a program designed to prevent HAB-related losses. In one such application, Larkin *et al.* (2011) found that Florida coastal residents demonstrated willingness-to-pay – through alternative payment vehicles – for programs to prevent, control, or mitigate Florida red tides, with higher willingness-to-pay for prevention over either control or mitigation. Other examples of non-market goods as they relate to HAB also may include the values that residents are willing to pay for enhanced coastal water quality for marine-related recreation, the existence of marine mammals found in nearshore waters, or unpolluted coastal waters necessary for proper ecosystem functioning.

One advantage of stated preference approaches in general is that such studies are tailored to measure user preferences exactly, as opposed to being constrained by available market data that may not relate to the preference of interest. Stated preference approaches to measure non-market economic values generally are referred to as using *contingent valuation* methods (CVM) because the results are *contingent* upon the hypothetical scenario that respondents are being asked to evaluate. For example, Larkin *et al.* (2011) report on the results of a CVM study that found that almost 50% of respondents (Florida residents) would be willing to pay an increase in property taxes of \$9–10 per \$100,000 of assessed value on average for a program to fund pilot studies of either biological or chemical means for the mitigation of HAB.

Although stated preference surveys are most useful because they can be tailored to measure exactly what information is needed, this flexibility also is the most common criticism for the approach. In other words, respondents may be asked to value hypothetical programs or changes with which they may have little experience or expertise. For example, several researchers have focused on characterizing the value of reducing the economic consequences of a "halo" effect, which comprises the avoidance by consumers of goods, such as seafoods, for which the likelihood of being tainted by HAB toxins is perceived to be risky or uncertain (Jensen, 1975). Whitehead *et al.* (2003) use CVM to ask mid-Atlantic seafood consumers whether they would vote for a mandatory seafood inspection program that would involve an increase in seafood prices. The authors found that an inspection program would be effective at moderating halo-type welfare losses associated with fish kills caused by *Pfiesteria* spp. In a follow-up study, Parsons *et al.* (2006) affirm this finding but show that, if seafood prices increase due to inspections, then the costs of avoiding seafood are reduced but not fully mitigated by the inspection program. Interestingly, there is significant uncertainty regarding whether *Pfiesteria* leads to human health effects when infected seafood is consumed. Consequently, it is unclear whether a seafood inspection program actually may help seafood consumers avoid risk. Notwithstanding the issue of the lack of respondent expertise, a large and growing body of literature exists to guide the successful use of stated preference approaches in generating valid economic values (Mitchell and Carson, 1989; Freeman, 1993; Bateman and Willis, 1999; Hanemann, 1999; Carson, 2000; Haab and McConnell, 2002; Champ *et al.*, 2003).

Using the broad distinction between market and non-market methods, 28 of the 36 studies reviewed have employed DOIs or revealed preference approaches to estimate economic losses (Table 8.1). The majority of these papers have relied upon data as reported by government agencies or provided by businesses or individuals. Four papers used IO models to determine the economic impacts of HAB on local communities. An additional six papers used stated preferences, most by surveying residents or agency staff. In addition, two papers used both the revealed preference and stated preference approaches by surveying respondents for past behavioral choices (e.g., recreational visits before, during, and/or after a red tide event) before surveying their preferences concerning a hypothetical change in coastal water quality (i.e., preferences for a program that could affect HAB and coastal water quality at residential and recreational sites).

8.4 Sources and Types of Data

The data used to derive empirical results comprise both primary and secondary data. *Primary data* include that collected directly from businesses (e.g., firm-level sales data), coastal managers (e.g., costs incurred for cleanup or monitoring), or individuals (e.g., how previous HAB changed purchasing and recreational choices, or how individuals value proposed programs to reduce HAB losses). *Secondary data* (primarily collected by government agencies for use by others) include quantitative information that has been previously collected, such as a time series of commercial fishery landings, recreational fishing trips, beach attendances, reported tourism revenues (restaurant and lodging industries), seafood sales, numbers of illnesses, environmental conditions, and HAB-related press releases, among others. The main sources of secondary data are government agencies. An additional source of secondary data is *metadata*, referring to data described and available through previous analyses and publications. Some HAB studies rely heavily on the findings of other analyses.

Of the 36 studies reviewed, 11 studies utilized primary data only, while 14 studies utilized secondary data only. Ten studies required the use of both primary and secondary data to achieve their research objectives. One study did not report the type of data used, and an additional study used metadata, or results (economic losses) reported from several previous studies.

Overall, the data used in these studies were obtained from a variety of sources. The secondary data were obtained mainly from municipal, state, and federal agencies, while the primary data were obtained from surveys administered by the research team. The surveys were administered to a wide range of users, depending on the particular nature of the study objectives.

8.5 Spatial and Temporal Scopes

Spatial scope refers to the geographic location of HAB events and the region of impacts. The spatial scope of studies focusing on economic effects of HAB has ranged from impacts on lakes, bays, or counties to national impacts (see Figure 8.3 for the distribution of the studies by jurisdiction). In between are impacts that encompass multiple counties (e.g., southwest Florida, northwest Florida, or Cape Cod) or multiple states (e.g., the U.S. mid-Atlantic region or New England). The relevant accounting stance depends on either the

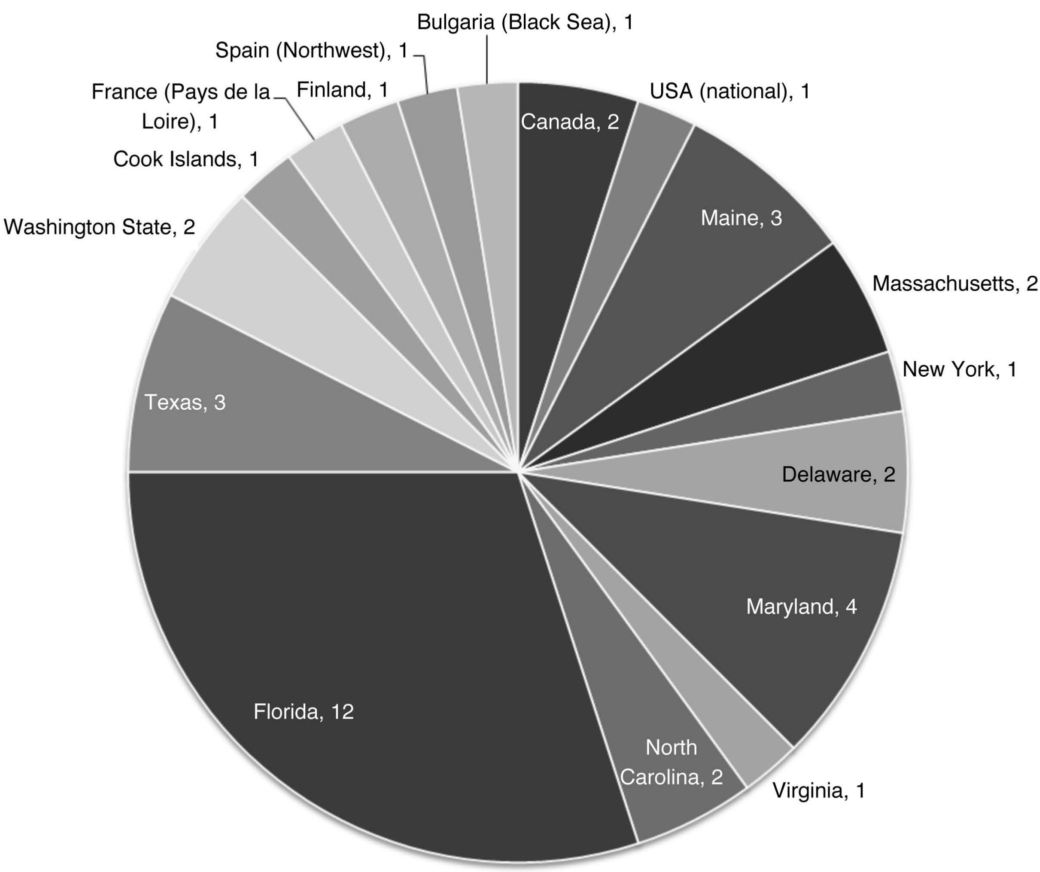

Figure 8.3 Jurisdictional distribution of the studies in Table 8.1.

geographic distribution of the HAB event or the impacted market area, such as local beaches or states where seafood consumers live or visit. In some studies, HAB impacts were assessed at a very fine spatial resolution. These studies often may be constrained by the available data on economic activity (e.g., issues of confidentiality may limit the availability of secondary data, or the spatial data simply do not exist on the level of resolution needed to assess very localized impacts). Thus, data constraints can impose limits on spatial resolution, increasing the difficulty of assessing the impacts of localized HAB events.

Temporal scope refers to the duration of HAB events and the time steps of measurement (i.e., days, weeks, months, and years). The temporal scope of studies focusing on the economic effects of HAB ranges from studies that attempt to quantify the impacts of a single bloom event, which could range from days to several months, to studies that span multiple years. Studies commonly analyze time series such as historic seafood landings or reported tourism revenues for tax purposes to identify changes in business activity or use patterns during HAB events. Assessing the impact of a HAB event at the appropriate level of temporal resolution sometimes may be difficult due to the lack of data. For example, secondary data often are collected periodically by state governments for tax or other reporting purposes. These data may be at a level of temporal resolution that does not match the time period needed to assess relatively short HAB. Or the data may not match the required spatial resolution for very brief, localized HAB events, such as zip-code-level tax data that are difficult to obtain due to issues of confidentiality. Data for shorter time periods or more localized coastal areas may need to be collected outside of existing agency data collection programs. Such primary data collection efforts can be time-consuming and costly for affected residents, businesses, government agencies, and researchers. Finally, the possible proprietary nature of high-resolution data may render access to such data problematic.

The studies reviewed exhibited an extensive range of temporal and spatial characteristics. The temporal and spatial scope of a study is obviously a function of the geographic range, duration, density, and toxicity of the HAB event being studied. The existing literature suggests that the economic effects of several major HAB have been investigated to date, and temporal and spatial data appear to be available to address the larger scale questions. Few economic analyses of smaller scale HAB events have been undertaken. Studies mainly used annual and monthly data, with weekly and daily data being extremely rare in terms of availability. On a spatial basis, of the 36 studies reviewed, six studies addressed HAB on a national scope, 18 on a regional or state level, six on a multi- or single-county level, and six on a local level.

8.6 Nature of the Hazard

The primary focus of this literature review effort was to summarize past economic research, which includes a range of algal species and toxins, and was initially focused on red tide events in southwest Florida. The term *red tide* often is used in a generic sense to refer to HAB, but only rarely do HAB, such as Florida red tide or *K. brevis*, lead to changes in water color due to blooms of localized high cell densities. Typically, analyses of the economic impacts of algal blooms are focused on the physical impacts (toxicity) to affected natural resources and humans.

There are six primary types of marine HAB toxins found in North America that may be taken up by shellfish or lead to morbidities or mortalities in finfish, marine mammals, sea turtles, seabirds, and humans. These toxins and their associated effects include:

1) Brevetoxins (neurotoxic shellfish poisoning [NSP])
2) Saxitoxins and their derivatives (paralytic shellfish poisoning [PSP])
3) Domoic acid (amnesic shellfish poisoning [ASP])
4) Okadaic acid (diarrheic shellfish poisoning [DSP])
5) Ciguatoxins (ciguatera fish poisoning [CFP])
6) Azaspiracids (azaspiracid poisoning [AZP]).

Red tides in the Gulf of Mexico have been dominated by *K. brevis*, which produces brevetoxins during a bloom. The economic effects of these HAB result from potential decreases in marine recreational activities, beachgoing, and human seafood consumption (red tides may also negatively affect those who passively value a healthy ecosystem and the services that resource provides). The red tide brevetoxins also can become airborne, affecting the respiratory system of humans residing and working in inland areas close to the bloom (Hoagland *et al*., 2009, 2014). Of the 36 papers that were reviewed, 13 reported economic effects associated with blooms of *K. brevis*.

With respect to shellfish consumption, toxic algae typically are undetectable by sensory analysis, such that the potential exists for poisoning and illness due to ingestion. Some toxins are also heat resistant, which means the toxin (and its effect) cannot be destroyed by cooking. The toxins associated with PSP, ASP, DSP, and other illnesses are the subject of 12 papers; in these cases, the toxins are associated mainly with cold-water species, and the primary human health impacts are linked through impacts on recreational or commercial harvests for consumption.

CFP is produced by various species of algae from the *Gambierdiscus* genus, which occur naturally in coral reef ecosystems and which are not necessarily associated with high cell density blooms. The ciguatera toxin is bio-accumulated via the food chain associated with coral reef species assemblages, and it is encountered by humans when top trophic level fish containing the accumulated toxins find their way into seafood markets. Of the papers reviewed, two addressed the economic consequences of CFP. An additional nine papers did not clearly specify or focus on a specific toxin or algae species.

8.7 Current Research Gaps

While much research on the economic consequences of HAB has been conducted, this discussion identifies 15 gaps that provide the potential for additional and critically needed work. The issues identified may also provide guidance regarding data that may need to be gathered before, during, and after future bloom events, particularly if a more complete assessment of the economic consequences of HAB events is of primary interest.

1) Time-series analyses routinely utilize historic data on fishery landings, reported earnings, and recreational trips obtained from business or government sources that encompass red tide events. Few studies have utilized both time-series and cross-sectional data; one example is the cost-of-illness study relating to blooms of the red tide *K. brevis* off the southwest Florida coast (Hoagland *et al.*, 2014). The use of the NOAA Marine Recreational Information Program (MRIP), a national data collection program based on coastal intercept surveys of recreational fisheries, is one promising source of panel data for future studies of HAB economic effects.
2) Linking HAB impacts with community demographic data would allow for an assessment of the distribution of HAB impacts across segments of the population. Regional economic frameworks, such as IO models, are particularly well-suited to describing the extent to which changes in economic activity affect demographic layers.
3) HAB events and their corresponding impacts are known to be affected by weather conditions, and yet the incorporation of weather data has been sparse (e.g., Morgan *et al.*, 2011). While the challenges of using these data have been documented, the richness of weather data should ensure that future studies consider testing for use in identifying threshold cell counts above which humans are likely to be affected (to test, refine, and possibly extend the level estimated by Morgan *et al.*, 2011), and to provide further insight to help efforts to advise the public and mitigate losses.
4) Data useful for assessing the impact of HAB on water-related businesses have been mainly secondary. Secondary data may limit temporal and spatial characterizations of HAB impacts. Developing data collection programs in real time would allow for a more complete assessment of HAB events on businesses and communities at higher levels of temporal and spatial resolution. Real-time data may require ongoing data collection, and implementing primary data collection may require the participation of local businesses that are vulnerable to the effects of HAB.
5) HAB events may exhibit a lagged impact on local business communities, particularly those in the tourism sector. This potential dynamic element of HAB event impacts has not been fully explored.
6) HAB events are characterized by a wide range of intensity and duration levels. Few studies have investigated the role of intensity, and none appear to address the potential for a nonlinear relationship between economic losses and duration. Establishing a relationship between HAB intensity and duration and economic impacts would provide coastal planners with additional information useful in making decisions regarding prevention, mitigation, and control options for HAB.
7) HAB may impact coastal property values and regional planning efforts. How have local property markets and planning efforts been compromised and impacted by HAB events across communities and over time? While

some very preliminary research has been conducted in isolated areas (cf. Bingham *et al.*, 2015), there is room for additional work given that property market data are readily available.

8) HAB may generate significant indirect impacts, leading to declines in finfish and shellfish stocks. For example, recent impacts of red tides on the reef fish resource in the eastern Gulf of Mexico led to reductions in official grouper biomass estimates. Future research is needed on how such impacts could influence fishery yields and management.
9) The HAB "research" literature comprises studies exhibiting a range of scientific rigor. Some studies estimate statistical relationships, while others execute simplistic calculations using secondary data or metadata. Although the latter may be appropriate in some situations, future research proposals should be more explicit in terms of exactly what is being measured and how, so that resource managers and stakeholders can better assess the credibility of study results.
10) The results of economic studies are reported inconsistently. Absolute losses are important but difficult to assess in terms of magnitude without baselines or assessments of relative changes. To facilitate comparisons across studies, it would be useful for results to be reported as percentage changes.
11) Time horizons and geographic areas often are defined only vaguely. Studies should identify both spatial boundaries and time horizons. Furthermore, the extent to which data are able to capture the independent effects of a HAB event should be made clear.
12) Potential researchers should explore alternative ways to combine revealed and stated preference approaches following recent advances in the non-market valuation literature.
13) Stated preference studies would be strengthened with surveys of representative populations to lessen the biases typically associated with such surveys.
14) Few studies have utilized existing models to take full advantage of past and related modeling efforts. Ecosystem-type models in particular (e.g., ECOSIM and Atlantis) could be used to assess the relative importance of HAB events compared to other environmental and anthropogenic stressors.
15) Most of the published research on the economics of HAB focuses on the costs to coastal and ocean users of reductions in their activities. More research is needed on identifying feasible policies to lessen these costs, such as policies to prevent, control, or mitigate HAB; to insure against HAB risks; or to increase the set of alternative opportunities for users. Policy responses can themselves be costly, and it is the combined costs of the hazard and the response that are relevant in terms of selecting appropriate courses of action. Estimates of policy alternatives, their effectiveness in terms of reducing the hazard, and their costs are clear priorities.

8.8 Conclusion

This chapter focuses on surveying the literature describing or analyzing the economic consequences of HAB events. Although we focus mainly on peer-reviewed examples of HAB economic analysis, an extensive "gray" literature exists that provides further insight into the array of HAB economic impacts. Within the existing literature, we address briefly some key issues associated with the research methodologies employed, the sources and forms of data utilized, the spatial and temporal scopes of analyses, the types of HAB and associated toxins, and the current research gaps. Each of the 36 studies has been annotated in Table 8.1.This review leads to suggestions for future research concerning the economic consequences of HAB. With continued increases in the nation's coastal populations and ongoing expansion of development along its coastal corridors, the likelihood of negative economic effects resulting from HAB events grows. More carefully designed research efforts, coupled with improved data, would help guide coastal decision makers and resource managers as they seek to understand better the causes, dynamics, and consequences of HAB events, regardless of the species and locations involved.

Acknowledgments

Porter Hoagland gratefully acknowledges funding from NSF Grant Nos. CNH 1009106 and PFI-BIC 1534054. Adams and Larkin acknowledge partial funding support for this effort through GOMA Grant UPN 11093017.

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