AN ASSESSMENT OF FLORIDA RED TIDE:
Causes, Consequences and Management Strategies

•

Frank Alcock, Ph.D.
Assistant Professor of Political Science
New College of Florida

Director, Marine Policy Institute at Mote Marine Laboratory

TECHNICAL REPORT #1190

August 2007

MOTE MARINE LABORATORY

1600 Ken Thompson Parkway • Sarasota, FL 34236 • (941)388-4441 • www.mote.org

Acknowledgements

The research and writing of this assessment were made possible by a grant from the New Amsterdam Charitable Foundation. Printing, dissemination and outreach activities associated with this assessment are being made possible by a grant from the Gulf Coast Community Foundation of Venice. Additional funding has also been provided by Mr. & Mrs. Ronald B. Morris.

The assessment is authored by Frank Alcock, Director of the Marine Policy Institute (MPI) at Mote Marine Laboratory. Dr. Alcock's Assigned Research Leave from New College of Florida, where he is an Assistant Professor of Political Science, provided the opportunity to conduct this assessment. The author would like to thank New College President Mike Michalson and Mote Marine Laboratory President Kumar Mahadevan for their support with this endeavor.

Chris Pettit, an MPI policy associate, provided research assistance for the assessment's regulatory framework section. Sherry Larkin at the University of Florida provided a helpful review of the initial draft of the economic impacts section. A number of Mote staff and research scientists provided constructive reviews and editorial suggestions at various stages. Lawson Mitchell was especially helpful with graphics and layout and Susan Stover provided invaluable assistance with reference checking.

The author would like to thank the following individuals for taking time to speak about the research and/or policy issues addressed in this assessment: Mark Alderson, Julia Birch, Larry Brand, JoAnne Burkholder, Don Cheney, Jill Copeland, Stuart DeCew, Chris D'Elia, Cindy Heil, Leon Kaganovskiy, Jason Lenes, Pat McDonald, Jack Merriam, Frank Muller-Karger, and Mario Sengco. In addition to these individuals the author benefitted from the opportunity to participate in a July 2006 Workshop on the State of Research on Red Tide in the Gulf of Mexico that was sponsored by the National Oceanic and Atmospheric Administration, Mote Marine Laboratory and the Florida Fish and Wildlife Research Institute.

Author Contact Information:

Frank Alcock
Marine Policy Institute at Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236
(941) 388-4441
alcock@mote.org

ABOUT THE MARINE POLICY INSTITUTE

The mission of the Marine Policy Institute at Mote Marine Laboratory is to strengthen the scientific basis of public policy and societal decision making for economic development and sustainability of our oceans and coastal ecosystems. Working closely with Mote scientists and other programs, the Institute conducts, integrates and communicates multi-disciplinary research on marine/coastal issues in a manner that produces salient, credible assessments and advice in policy (legal, economic, social) to decision-makers, stakeholder groups, and concerned citizens.

Dr. Frank Alcock is Director of the Marine Policy Institute. Dr. Alcock, Assistant Professor of Political Science at New College of Florida, holds a Ph.D. in Political Science from Duke University, an M.A. in International Affairs from George Washington University and a B.A. in Economics from the State University of New York, Binghamton. His experience traverses both governmental and academic research on sustainable development and trade and global environmental politics with a focus on oceans and marine policy. He was a Belfer Fellow at the Kennedy School of Government, Harvard University and an active member of the human dimensions of global environmental change research community.

Barbara J. Lausche, J.D., is the Institute's Deputy Director. She received her J.D. from the Columbus School of Law and has 30 years of experience with government and non-governmental organizations in the U.S. and internationally. Lausche has worked with multi-disciplinary teams of scientists building institutional capacity and legal frameworks. She has worked with the Environmental Protection Agency, the Congressional Office of Technology Assessment, and was senior environmental staff with the World Bank. Lausche serves on the Board of the Island Resources Foundation, co-founded the Science and Environmental Council of Sarasota County and served as its honorary Executive Director for five years. She is a member of the D.C. Bar, the Commission on Environmental Law, the International Union for Conservation of Nature and Natural Resources and Caribbean co-chair of their Specialists Group on Oceans, Coasts and Coral Reefs.

Dr. Michael Orbach is the Institute's Special Advisor. Dr. Orbach, Professor of Marine Affairs and Policy at the Nicholas School of the Environment and Earth Sciences at Duke University, holds both a Ph.D. and M.A. in Cultural Anthropology from the University of California, San Diego and a B.A. in Economics from the University of California, Irvine. He has worked as a Cultural Anthropologist with the National Oceanic and Atmospheric Administration, has held several Governor's appointments to environmental Boards and Commissions, as well as several appointments with the National Academy of Sciences. Dr. Orbach was an advisor to both the Pew Oceans Commission and the U.S. Commission on Ocean Policy and is a former President of the Coastal Society and the Southern Association of Marine Laboratories, Chairman of the Board of Directors of the Surfrider Foundation and a member of the Board of Directors of the Ocean Conservancy.

Dana O'Mara, M.S., serves as the Marine Policy Institute Program Manager. She holds an M.S. in Oceanography and Coastal Sciences from Louisiana State University. O'Mara has research experience in coastal management, marine policy and economic issues pertaining to the Gulf of Mexico region and beyond. She received a National Oceanic and Atmospheric Administration Coastal Management Fellowship to help develop a Shoreline Access Plan and a Shoreline Economic Analysis for the state of Texas.

AN ASSESSMENT OF FLORIDA RED TIDE:
Causes, Consequences and Management Strategies

Table of Contents

Executive Summary 1

Introduction 2

The Causes of Florida Red Tide 3
- Red Tide Basics: Bloom Dynamics and Physiology 3
- Historical Trends 3
- Coastal Pollution and Florida Red Tide 4
  - Reasons for Caution with Respect to Linkage 5
  - Reasons for Concern with Respect to Linkage 6
  - Moving Forward 8

Consequences: Impacts to Marine Life and Human Health 10
- Brevetoxins 10
- Impacts to Marine Life 10
- Impacts to Human Health 11

Consequences: Economic Impacts 13
- Variation in Estimates 13
- National Estimates of Harmful Algal Bloom impacts 13
- Estimates of Florida Red Tide Impacts 14

Management Strategies 16
- Prevention: Measures to Reduce the Incidence or Extent of Red Tides 16
  - Exercising Precaution 16
  - Reducing Non Point Source Pollution 16
- Control: Measures to Kill, Neutralize or Remove Red Tide from the Water Column 18
  - Five Key Evaluative Criteria 19
  - Flocculation 20
  - Ozone 20
  - Other Chemical and Biological Agents 22
- Mitigation: Measures to Reduce the Impacts of Red Tides 22
  - Improved Monitoring Capacity 22
  - Human Dimensions Research 23
  - Public Education and Outreach 23

Governance Issues 24
- The Regulatory Framework for Florida Red Tide 24
  - Federal Governance 24
  - State Governance 24
  - Local Governance 26
- The Florida Harmful Algal Bloom Task Force 26
- External Review 27

Conclusion 29

Appendix: Q&A 30

References 32

Acronyms 38

Glossary 39

EXECUTIVE SUMMARY

Our quality of life in Southwest Florida can be improved with a more comprehensive and sustained management strategy for Florida red tides. It can also be improved by reducing coastal pollution. Both agendas have significant implications for the health of our marine environment and the coastal economies that depend upon them. In recent years, their potential overlap has become a focal point of controversy. Coastal pollution is often depicted as either the primary cause of red tides or as something that's incapable of affecting them. Neither position stands up to scrutiny.

Red tides have long been a fixture of the West Florida Shelf ecosystem and most scientists agree that the initiation of blooms and significant stages of their development occur offshore and deep in the water column. Once a bloom moves inshore, it may benefit from land-based nutrient fluxes. These fluxes occur naturally but they can also be exacerbated by coastal pollution. Reducing nutrients from land may ease the severity and duration of red tides, and reduction should be part of a comprehensive management strategy that responds to red tides. Reduced nutrient loads and better water quality will also generate ecological, social and economic benefits that are independent of any connection to Florida red tides.

It is imperative that scientists, policymakers and stakeholders move beyond polarized debate surrounding the links between coastal pollution and red tide. Conclusive scientific evidence of a strong linkage between coastal pollution and red tide blooms would no doubt generate political momentum for a pollution-reduction agenda. However, the nature of nutrient conditions on the West Florida Shelf and the variety of nutrient sources that likely contribute to red tides make it very difficult to pinpoint or assess the relative significance of each source. Conclusive evidence remains elusive but Florida needs to act now. Florida needs to reduce nutrient loads to its watersheds for reasons that go beyond red tide and it needs to develop a comprehensive management strategy for red tides that goes beyond reducing coastal pollution.

The Marine Policy Institute (MPI) at Mote Marine Laboratory encourages the scientific community to intensify its focus on the role of nutrients in red tide events. But we caution policymakers and stakeholders against thinking about the links between coastal pollution and red tide in a vacuum. More thought needs to be given to the regulatory processes by which coastal pollution will be reduced. The Florida Department of Environmental Protection is currently overhauling water quality standards for the state's watersheds that will largely dictate improvements. Local ordinances can supplement these standards but policymakers, stakeholders and citizens should not lose sight of the importance of statewide efforts. They should also not lose sight of the fact that Florida needs to address a broad portfolio of concerns that involve land-sea interactions. Red tide is just one concern among many.

The MPI recommends a multi-pronged approach that combines precautionary measures to curb coastal pollution with continued research into a diversified suite of control technologies and an expansion of measures to mitigate the impacts of red tide blooms. Expanded mitigation measures should include a robust program on monitoring, detection and forecasting along with a robust human dimensions research agenda and an aggressive education and outreach program. Human dimensions research should include projects that assess the impacts of chronic exposure to red tide, projects that measure public perceptions and knowledge about red tide, projects that measure economic activity before, during and after blooms, and projects that improve upon interagency coordination and emergency response and recovery plans.

Finally, the MPI recommends that the Florida Harmful Algal Bloom Task Force be redesigned, funded and reconvened, and that a mechanism be developed to provide for periodic external review of Florida's Harmful Algal Bloom research and management programs. In addition to strengthening these programs, an external review should help to build trust with disaffected stakeholder groups.

Introduction

Red tide blooms have long afflicted the west coast of Florida but many believe that the problem is getting worse. For the past 20 years, our region has been subjected to debilitating blooms on a near-annual basis. The most severe of these blooms have persisted for more than a year and have resulted in massive fish kills, large underwater dead zones, significant marine mammal mortalities, adverse impacts on human health and substantial economic losses.

As red tides have continued to take their toll on Southwest Florida, public frustration has intensified. Coastal communities want a cause identified or a cure unveiled. Policymakers are also frustrated. Decades of research have yielded much knowledge about Florida red tides, but the results fail to identify a primary nutrient source behind the blooms. State and local government officials have expressed their desire to address the problem but little consensus has emerged about the most appropriate course of action.

Florida red tide presents itself as a priority issue for the newly established Marine Policy Institute (MPI) at Mote Marine Laboratory. The MPI's mission is to conduct, integrate and communicate multi-disciplinary research on marine policy issues in a manner that produces salient, credible assessments and advice to decision-makers and the public. The need for these services on the issue of red tide is clear. The science of Florida red tide is complex, and strongly held viewpoints have contributed to the politicization of scientific debates. The MPI steps in with the goal of facilitating a constructive dialogue among different constituents and forging some consensus regarding the benefits and limitations of different management options.

The MPI initiated its assessment of Florida red tide with the following tasks in mind:

- Survey the broad range of research activity pertaining to Florida red tides;

- Translate research results into language that can be understood by policymakers, stakeholder groups and the general public;

- Synthesize and integrate the most pertinent research findings in a manner that responds to the most pressing questions put forth by these groups;

- Assess alternative management strategies and existing regulatory frameworks;

- Provide guidance.

Importantly, this assessment does not attempt to provide a definitive resolution to all of the questions it addresses. Definitive answers are possible in some instances but in many others they are not. What the assessment attempts to do is to contribute to a more constructive dialogue by clarifying areas of agreement and disagreement on these questions and outlining what is known, what is unknown and how we might learn what we don't know. We hope our audience will look upon the assessment as a repository of research and management insights and a point of departure for further discussion.

How to Read This Assessment

This assessment is broken down into several sections that cover the most relevant and important aspects surrounding Florida's red tide. Each section also includes several subsections.

"The Causes of Florida Red Tide" addresses bloom dynamics and physiology with a view toward understanding the causes of red tide. After providing some basic background, the section directs its attention toward pressing questions regarding historical trends and coastal pollution.

"Consequences: Impacts to Marine Life and Human Health" addresses the consequences of red tide with a focus on the toxicology of *Karenia brevis* and its impacts on marine life and human health.

"Consequences: Economic Impacts" extends the discussion of the consequences that red tides have on the economy and the need for better measures to understand the impacts.

"Management Strategies" addresses strategies that include prevention, mitigation and control measures and the implications for each.

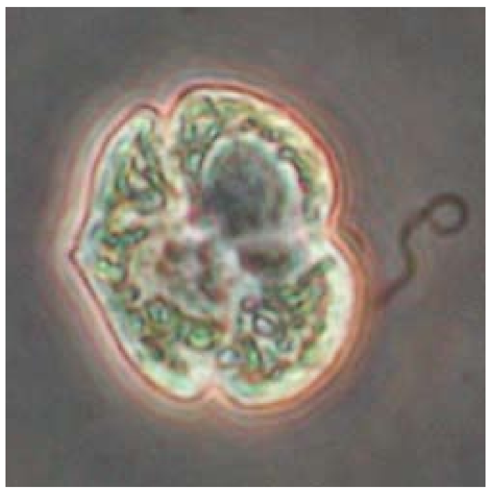
"Governance Issues" provides an overview of the regulatory framework pertaining to red tide issues and suggests measures to strengthen governance functions.

"Conclusion" revisits the assessment's major points.

The Causes of Florida Red Tide

Red Tide Basics: Bloom Dynamics and Physiology

Florida red tides are caused by the toxic dinoflagellate *Karenia brevis* (previously known as *Gymnodinium breve*), a species of phytoplankton found on the West Florida Shelf. It is commonly present in background concentrations throughout the Gulf of Mexico. It can survive in water temperatures ranging from 9˚C to 33˚C (48˚F to 92˚F) with optimum growth occurring between 22˚C and 28˚C (72˚F and 82˚F) and in a wide range of salinities from 24% to 37% with optimum growth occurring between 31% and 37% (Steidinger et al. 1998). Growth rates may also be affected by sunlight and shade may play an important role in the development of blooms (Walsh et al. 2007).



Microscopic view of *Karenia brevis* cell

Scientists who study the life cycle of *K. brevis* divide red tide blooms into four stages: initiation, growth, maintenance and termination. Initiation is believed to occur offshore and at depth. *K. brevis* cells are remarkably opportunistic when it comes to metabolizing nutrients and they make use of a broad range of organic and inorganic material. Although opportunistic, the growth rate of *K. brevis* cells is slow compared to that of many other species of phytoplankton. *K. brevis* cells typically undergo one cell division every two to three days whereas a number of other species of phytoplankton undergo three to four divisions a day. Blooms can develop in deeper levels of the water column before portions migrate to the surface. Prevailing ocean and wind currents can transport the bloom closer to shore or move it along the coast. Given that blooms initiate and develop in a nutrient-poor environment, the blooms often maintain themselves by recycling or regenerating nutrients. Factors such as predation, changing nutrient ratios, limited nutrient availability and dilution of water masses have been suggested as precursors to bloom termination. Relief to coastal areas also results from the transport of the bloom out of the area (Tester and Steidinger 1997, Steidinger et al. 1998).

Historical Trends

Although long-term historical trends remain a topic of debate among harmful algal bloom (HAB) researchers (ICES 2007), a number of authoritative scientific organizations have stated that harmful algal blooms are getting worse around the world (U.S. Commission on Ocean Policy 2004, HARRNESS 2005, FDEP 2006). Some of the factors believed to play a role in this worldwide trend include nutrient enrichment, or eutrophication, resulting from population growth and land use practices, and warmer water temperatures due to global climate change. Although the general trend appears to be worsening, trends for specific HABs can embody more uncertainty. This is particularly true for HABs that start offshore like *K. brevis*.

Southwest Florida has endured red tide blooms on a near-annual basis over the past two decades and the 2005 bloom was one of the most severe on record. However, Florida red tide blooms of similar intensity and duration have been confirmed as far back as 1948-49, and anecdotal evidence suggests that severe blooms have scourged the region for hundreds, if not thousands, of years. There is broad consensus that Florida red tides have been especially active in recent years but putting this decade into historical perspective is extremely difficult due to a lack of data suitable for exposing historical trends.

Even though red tide blooms have long been a fixture of the West Florida Shelf marine ecosystem, many people believe that they are getting worse in terms of frequency, intensity and duration. Such perceptions have been reinforced by increased media attention on the topic and a recently published article in the scientific journal *Harmful Algae* (Brand and Compton 2006).

In the journal article, Brand and Compton argued that Florida red tides were substantially more abundant in the 1994-2003 period than they were in the 1954-63 period. The authors also noted changes in seasonal patterns of Florida red tide blooms and their relative intensity inshore vs. offshore. The authors hypothesized that increased nutrients from terrestrial sources can explain these patterns. Brand and Compton based their conclusions on an analysis of a historical red tide database compiled and maintained by the Florida Fish and Wildlife Research Institute (FWRI). FWRI has argued that the database is generally unsuitable for analyzing historical trends because of the nature of the data and the methods by which they were collected prior to 1998. On other questions pertaining to the origins, growth and trajectory of past blooms, the FWRI suggests that the database can be quite helpful (FWRI 2007b).

One of the fundamental tenets of scientific inference concerns the need for an unbiased sampling protocol. Bias occurs when samples are not representative of the broader population being studied. In order to infer historical trends from red tide data, researchers must ensure that the timing and location of sampling efforts do not vary in response to expectations or observations of red tide. Red tide researchers also must make every effort to ensure that variation in their measurements of red tide reflects actual patterns of change in red tide blooms rather than changes in the way they are studying those blooms. Consistency and reliability in sampling procedures are essential to these efforts.

The majority of historical red tide measurement data that exist in the FWRI database consist of event response data — that is, data were gathered only after a bloom had already been verified in a particular place at a particular time. Systematic sampling protocols — those that take measurements at consistent locations and consistent periods of time were only used sporadically prior to 1998. With the increase in coastal population since the 1950s and the advances in detection technologies (including satellite imagery) it is difficult to determine whether changes in event response data truly reflect changes in the nature of red tide blooms or our better ability to detect them. Attempting to make inferences from datasets that mix event response data with systematically collected data can be especially problematic. Finally, the variety of organizations collecting red tide data, the types of information collected and the measurement techniques used have varied considerably over time in Southwest Florida. This introduces additional concerns with respect to the consistency and reliability of the data compiled by FWRI.

Red tide blooms have long plagued Florida's coastline.
This picture shows a fish kill from the 1960s.

Can these sampling concerns be alleviated through the application of statistical techniques? This question is at the center of the debate surrounding the FWRI database. In their analysis, Brand and Compton employed a set of statistical techniques to reduce the sampling bias. Statisticians commissioned by the FWRI to analyze both the Brand and Compton article and the FWRI database have called into question the techniques used by Brand and Compton as well as their conclusions (FWRI 2007d).

The MPI is not qualified to resolve this ongoing debate but given the accessibility of the database and transparency of the statistical techniques used by Brand and Compton, qualified experts will be able to assess the relative merits of these competing claims.

Importantly, the FWRI position that the pre-1998 data in the historical database are unsuitable for determining historical trends implies that we will not be able to confirm for the foreseeable future whether or not Florida red tides are indeed worsening. Under such circumstances, the MPI encourages policymakers to operate under the assumption that Florida red tides may very well be getting worse.

Coastal Pollution and Florida Red Tide

Coastal pollution has been a focal point of contention between some scientists and stakeholder groups. Some have expressed doubts over the importance of terrestrial nutrient sources in explaining red tide blooms and others believe them to be a major contributing factor. In many cases the disagreement has been semantic with scientists equating "cause" with initiation and stakeholders equating "cause" with the appearance of blooms in coastal regions. This debate, at times quite tense, can evolve into a more constructive dialogue as both sides better understand and acknowledge the reasons for contending viewpoints.

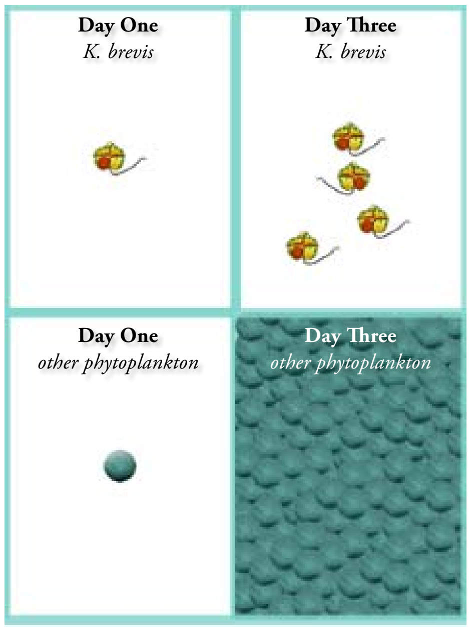
K. brevis is highly adept at utilizing both organic and inorganic nutrients. The relative importance of different nutrient sources varies over the stage of a bloom and it is possible that the specific combination of nutrient sources that are responsible for a major bloom varies from year to year. Most scientists agree that red tide blooms initiate offshore before being transported inshore by wind and ocean currents. They express skepticism that terrestrial nutrients affect the early stages of a bloom. However, when a bloom moves inshore, most acknowledge that runoff can help maintain the life of a bloom or affect its growth. How much a role these sources play remains unclear. Complicating the issue further, coastal nutrients can be categorized as either "natural" — present during even pre-historic times — or anthropogenic — the result of human activities. Distinguishing between the two can be difficult in nature.

Reasons for caution with respect to linkage

For those who perceive coastal pollution to be a major contributing factor to the occurrence of red tide blooms, it is important to acknowledge that there is a substantial amount of research on the physiology of *K. brevis* cells and transport of red tide blooms that cautions against arguments linking coastal pollution to red tide.

One of the most important features of *K. brevis* that rarely registers in public debates is its slow growth rate.

K. brevis cells are remarkably opportunistic in using a broad range of nutrients. They are by no means picky eaters. But their slow growth rate provides other phytoplankton species better access to available nutrients in eutrophic, or high-nutrient, environments. When nutrient levels are lower, in oligotrophic environments, *K. brevis* is better suited to compete with these other phytoplankton species. Its niche, or ecological specialization, seems to be the use of organic nutrients and very low concentrations of inorganic nutrients (FWRI 2007c). Simply stated, *K. brevis* can survive and even thrive where other species cannot.



K. brevis cells multiply at a significantly slower growth rate when compared to other species of phytoplankton. Over a three day period one *K. brevis* cell will develop into four or five cells. Over the same period one cell of other phytoplankton species can develop into thousands of cells.

These observations provide some insight into an important puzzle for Florida red tide researchers: how does *K. brevis* come to dominate an ecosystem when it should be out-competed by other species of phytoplankton that grow more rapidly? These insights also pose a problem for arguments claiming that coastal pollution causes Florida red tides.

Inland waterways and coastal estuaries contain a number of phytoplankton communities that will absorb most nutrients found in coastal runoff. It is difficult to specify a plausible delivery mechanism that allows nutrients from runoff to bypass a gauntlet of other phytoplankton species and become accessible to *K. brevis* during its initiation and development away from the coastline. This makes theories about nutrient-enriched coastal runoff pouring into the Gulf and triggering red tide blooms problematic. For blooms that have established themselves along the coastline the picture is more complex.

Before the mid-1970s, scientists believed that red tide blooms initiated and grew around inshore passes. However, after a review of historical data from blooms in the 1950s and 1960s, scientists concluded that red tide blooms originated about 10 to 50 miles offshore (18 to 74 km) on the mid West Florida Shelf (Steidinger et al. 1998). Although a few scientists have questioned whether the offshore initiation theory should be accepted as fact, the use of satellite data and more vigilant monitoring programs have since confirmed a number of offshore blooms and tracked their transport to inshore waters by ocean and wind currents. Importantly, red tide blooms can develop throughout the water column and what we witness — and track — at the surface is often an incomplete picture of the scale and movement of what is happening with a given bloom below the surface (Weisberg and He 2003; Walsh et al. 2003).

It often appears that small red tide blooms move inshore, then rapidly increase in scope and intensity around inlets. This reinforces the perception that these blooms are being fueled by coastal runoff. However, blooms tend to concentrate along a rapid change in water density such as temperature and salinity fronts that mark the boundary between two distinct water masses. Early stages of blooms have been found associated with density gradients well offshore. Density gradients are also found around inlets and in the mouths of estuaries. Given what is known about the growth rates of *K. brevis* and the physical oceanography of the West Florida Shelf some scientists suspect that people are witnessing upwelling and accumulation more than expansion and intensification.

So what nutrient sources do scientists think account for red tide blooms if not coastal runoff? There have been dozens of theories involving suspected nutrient delivery mechanisms for *K. brevis*. Scientists stress that these mechanisms are not mutually exclusive. Many likely operate in concert with one another. Scientists also stress that no single source can account for all the nutrients required to sustain a major bloom (Vargo et al. 2007; Walsh et al. 2007).

Apart from land-based nutrient sources there are a handful of atmospheric and oceanic sources that are receiving increased attention from scientists. Upwellings of deep, nutrient-enriched water along the continental shelf are viewed as playing a potential role in the initiation of offshore blooms. These nutrients result from the accumulation and reprocessing of marine life from the water column. Robust nutrient reservoirs are common to most large water bodies such as oceans and gulfs below their thermoclines, where colder, saltier water mixes with warmer, fresher water. While there seems to be some correlation between upwelling in the Gulf of Mexico and a couple of red tide blooms, recent FWRI data suggest that these upwellings can benefit other phytoplankton communities as much — if not more — than they benefit *K. brevis* (C. Heil, pers. comm. March 2007; J. Lenes pers. comm. June 2007).

A second significant source of nutrients may be *trichodesmium*. *Trichodesmium* is a cyanobacteria found throughout the world's oceans. *Trichodesmium* blooms often precede and/or accompany *K. brevis* blooms. *Trichodesmium* can provide significant nutrients to *K. brevis* through a process known as nitrogen fixing. With adequate supplies of iron, *trichodesmium* can fix nitrogen from the atmosphere and excrete it in a form that can be used by *K. brevis*, subsequently resulting in the growth of a red tide bloom. In recent decades, increased desertification in Africa and the resulting transoceanic dust clouds have meant more iron deposits in the Gulf of Mexico. The increases in iron deposits seem to coincide with *trichodesmium* blooms that are accompanied by red tide (Mulholland et al. 2006; Walsh el al. 2007). Notably, rainfall may facilitate nutrient delivery mechanisms involving *trichodesmium* in addition to increasing coastal runoff (J. Lenes pers. comm. June 2007).

A third significant source of nutrients is rotting fish. Since dead fish often drift to the bottom before floating to the top, a massive fish kill triggered by a bloom could conceivably lead to the dispersal of a large amount of nutrients throughout the water column. Rough estimates of the biomass of fish killed during a red tide bloom indicate that this source could be a significant contributor to the overall nutrient budget (Vargo et al. 2007).

It is highly likely that the predominant nutrient source changes over the course of a bloom and it remains unclear whether a particular combination of sources is common to all blooms (Walsh et al. 2007). The table on page 7 attempts to capture some of the most important ingredients in the recipe for Florida red tides.

Reasons for concern with respect to linkage

For those who are quick to downplay the potential links between coastal pollution and red tide, it is important to acknowledge some concerns and observations that have been expressed by stakeholders and scientists.

Regardless of the factors responsible for initiating a bloom, once it moves inshore, the bloom will be able to use any nutrients that it can access. Even if a number of important stages of red tide bloom development occur beyond the reach of coastal runoff, any contribution that pollution makes to the frequency, scope, intensity and/or duration of a red tide bloom once it arrives inshore is of consequence. If coastal pollution does nothing more than extend the duration of red tide blooms, it still remains of paramount concern because the duration of a given bloom is often the most significant factor in its overall impact on coastal communities.

Although there is no conclusive scientific evidence linking specific sources of coastal pollution to Florida red tides, there are a number of unresolved questions that caution against dismissing it as inconsequential. The questions pertain to the amount of nutrients being discharged into watersheds and groundwater tables from non-point sources, the range and intensity of terrestrial nutrient fluxes into the Gulf of Mexico and the fate of dissolved organic vs. inorganic nutrients as they move through the ecosystem.

In their analyses of sediment cores from Charlotte Harbor, Turner et al. (2006) conclude that the present nitrogen loading to the estuary is about three times what it was before the 1800s. The analyses also suggest that improved water quality treatment facilities and land use practices resulted in stable or slightly lower nitrogen loading from rivers between 1980 and the early 1990s. It projects higher loads after 1998 because of continued population growth.

Estimated nitrogen loads to Tampa and Sarasota bays have been lowered substantially since the 1970s, although assessments of Southwest Florida estuaries from Venice through the Ten Thousand Islands paint a bleaker picture of current water quality conditions (Conservancy of Southwest Florida 2005; Charlotte Harbor National Estuary Program 2005; Sarasota Bay Estuary Program 2006; Tampa Bay Estuary Program 2007). This seems consistent with the notion that the net changes to nutrient loads in Florida's waterways since the 1972 Clean Water Act vary from watershed to watershed with predominant composition and sources of nutrient loads changing over time.

Recipe for Florida Red Tides

Ingredients	Impact
Initial Factors	
Upwellings	Upwellings of deep, nutrient enriched water along the continental shelf are viewed as playing a potential role in the initiation of offshore blooms.
Saharan Dust	Dust clouds from the Sahara Desert contain iron. When deposited in the Gulf of Mexico the iron can boost *trichodesmium* blooms and their production of nutrients.
Rainfall	Rainfall may enhance a number of nutrient delivery mechanisms including those that involve atmospheric deposition (see *trichodesmium* discussion) and terrestrial fluxes.
Proximate Nutrient Sources	
***Trichodesmium* Blooms**	*Trichodesmium* blooms often precede and/or accompany Florida red tides. *Trichodesmium* can provide significant nutrients for red tide blooms through a process known as nitrogen fixation. *Trichodesmium* uses iron to fix nitrogen from the atmosphere and excrete it in a form that can be used by a red tide bloom.
Grazing and Excretion	Similar to the above mechanism whereby nitrogen is created as a byproduct of *Trichodesmium* blooms, other species of plankton consume one another and excrete nutrients as byproducts of their metabolic processes.
Terrestrial (land-based) Fluxes	Terrestrial fluxes can include a variety of organic and inorganic nutrients that result from human activities as well as natural physical processes. While a substantial portion of these nutrients are absorbed before escaping into the Gulf, some may become accessible to red tides.
Benthic (sea bottom) Fluxes	The benthos or sea bottom serves as a significant reservoir of nutrients. A rich variety of marine life utilizes these nutrients but it remains unclear whether or not significant amounts can flux or escape into the water column in a manner that allows *Karenia brevis* to access them.
Self-Sustaining Mechanisms	
Regenerated Nutrients	*K. brevis*, in association with bacteria, may be particularly adept at regenerating nutrients from metabolic byproducts as well as the nutrients that are released when cells die. While this should not contribute to bloom growth it may allow red tide blooms to maintain themselves until more nutrients become available.
Dead Fish	Dead fish can disperse a large amount of nutrients throughout the water column. As red tides become larger and more intense they begin to kill more fish. The fish kills result in the release of additional nutrients that can intensify the bloom.

The above table highlights some of the main factors involved in the nutrient delivery mechanisms that can contribute to the initiation and development of Florida red tides. Each factor is depicted as an ingredient with an accompanying description of its impact. Note that some ingredients (*trichodesmium* blooms, coastal runoff) are enhanced by others (dust, rainfall). Some ingredients may be more or less important at different stages of a bloom and it is unlikely that red tide blooms are dependent on any single ingredient – they can still occur when one or more are missing. The more ingredients that are present, however, the greater the likelihood of a bloom.

Statewide, substantial improvements have been made with respect to controlling point source pollution over the past 30 years, but non-point source pollution appears to have steadily increased over this time. Increased levels of nutrients and decreased levels of dissolved oxygen continue to persist in many of Florida's waterways (FDEP 2006).

The relationship among changing patterns of land use, associated nutrient loads and their impacts on macroalgal and phytoplankton communities is complex. Some changes to coastal algal communities reflect less coastal pollution, while some reflect more. One study links the reduction of nutrient loads from point source pollution to lower total phytoplankton densities and to a declining dominance of a single opportunistic species in the Tampa Bay area (Johansson and Lewis, 1992). Another study links increases in macroalgal populations in the coastal waters of Lee County to terrestrial fluxes that are believed to be associated with non-point sources (Lapointe and Bedford 2006). Another study links changes in background nutrient ratios to both land use practices and algal communities across a long stretch of coastline in Southwest Florida (Heil et al. 2007). Given these findings it seems plausible that land use activities could affect nutrient conditions in a manner that renders particular coastal regions vulnerable to takeover by an incoming red tide bloom. And once blooms arrive inshore, terrestrial nutrient fluxes can contribute to them.

A number of potential relationships between terrestrial nutrient fluxes and Florida red tides have been examined or hypothesized. One study does provide evidence of a correlation between rainfall, river flow and red tide duration (Dixon 2003) and additional anecdotal data on specific blooms are suggestive (L. Brand, unpublished data). Rainfall and river flow should increase terrestrial runoff, which can send pulses of a variety of organic and inorganic nutrients downstream. While a substantial portion of these nutrients will be absorbed by other phytoplankton communities before reaching a red tide bloom, some could become accessible to red tides.

Other arguments propose indirect mechanisms linking coastal pollution and red tide through groundwater releases. Hu et al. (2006) argue that Florida's active 2004 hurricane season could have triggered pulses of groundwater release in offshore springs that provided substantial nutrients to the 2005 red tide bloom. There has also been speculation about the potential for polluted groundwater releases closer to the shoreline and their potential impact on blooms (Lapointe and Bedford 2006; Paytan 2006). Additional speculation exists regarding the potential for terrestrial nutrient fluxes to be stored in benthic sediments in a manner that can be accessed by *K. brevis* (Brand and Compton 2006; L. Brand, pers. comm. June 2007). More research needs to be conducted before these hypothesized nutrient delivery mechanisms can be ruled out as significant contributors to the overall nutrient budget.

A final area of concern involves the relative importance of dissolved organic nutrients for *K. brevis*. As noted earlier, recent research suggests that *K. brevis* is adept in using dissolved organic nutrients (Bronk et al. 2004; Bronk et al. 2006). Urea, in particular, is readily metabolized by *K. brevis*. In recent decades, the composition of many fertilizers has shifted toward higher urea content. Scientists have suggested that this shift may be linked to increased coastal eutrophication and higher incidences of certain types of algal blooms (Anderson et al. 2002; Glibert et al. 2006). Urea concentrations have not been monitored with any regularity in the coastal waters of Southwest Florida until recently and this has alarmed some stakeholders who point to the potential impacts of fertilizers (Zollo 2006).

Moving Forward

The amount of data collected on red tides and associated environmental conditions has increased substantially over the past few years to the point where data collection has outpaced data analysis. A rigorous analysis of recently collected data can be expected in the next couple of years along with a renewed emphasis on nutrient dynamics in conjunction with a new $4.7 million grant from NOAA to address nutrient questions (NOAA 2006).

There are three approaches that the red tide research community might consider in helping to resolve unanswered questions relating to nutrient dynamics:

- Sharpen the focus on nutrient uptake during the course of a bloom.

This approach would imply an expansion of efforts to track and monitor red tide blooms and an accompanying intensification of event sampling efforts in terms of their spatial and temporal coverage. This approach could prove especially helpful to isotopic tracing efforts. Isotopic tracing is a technique used to trace chemical compounds from different sources. It has recently provided some clues to the nutrient sources used by *K. brevis* (Havens 2004; Lapointe and Bedford 2006). The technique's utility is hampered, however, when a mobile organism quickly utilizes its available nutrients and where more than two sources are potential contributors of nutrients. Both conditions appear to be present in the case of *K. brevis* but both can be accommodated - to a certain degree - by more frequent sampling over a longer period of a bloom's life cycle (C. Heil, pers. comm. June 2007).

- Sharpen the focus on specific areas where nutrient terrestrial fluxes and *K. brevis* are suspected to interact.

Studies that target estuaries, inlets and shoreline coastal areas may yield insights on terrestrial nutrient fluxes that have escaped detection in laboratory analyses and theoretical discussion. An intense focus on these areas would also allow for long-term studies of red tide's impact on particular marine species and ecosystem habitats.

- Sharpen the focus on different sources of coastal pollution in an effort to more accurately assess their magnitude, disposition and impacts on coastal ecosystems.

While many forms of coastal pollution have been reduced over the past few decades, non point source pollution has increased. Net changes to nutrient loads vary from waterway to waterway. Importantly, we do not monitor the vast majority of non point sources of pollution as much as we estimate them (FDEP 2006). If we are underestimating non point source pollution and associated nutrient loads and these loads are affecting our coastal environment in subtle but important ways then it follows that coastal pollution could be directly or indirectly affecting patterns of red tide.

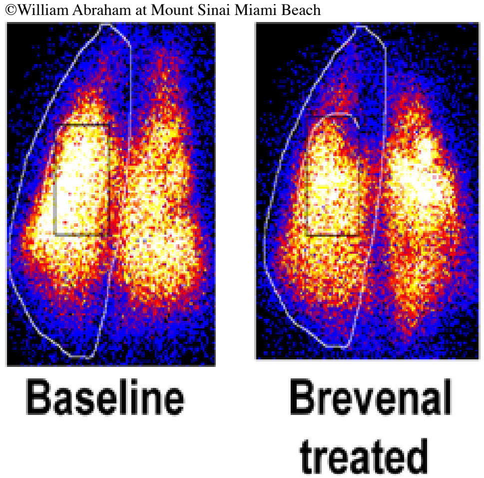
In sum, much of what we know about Florida red tide casts doubt on the notion that coastal pollution can trigger the initiation or development of red tide blooms offshore. This does not mean that terrestrial nutrient sources are unrelated to red tide blooms. Once blooms arrive inshore, there are a number of reasons to suspect that coastal pollution can exacerbate them, as has been observed for other phytoplankton and macroalgal species. Resolving the slow growth rate of *K. brevis* with its apparent ability to dominate a phytoplankton community remains a key research puzzle. Vigorously testing a variety of terrestrial nutrient hypotheses will be necessary to confirm or refute them and dispel lingering suspicions and uncertainties.

Consequences: Impacts to Marine Life and Human Health

Karenia brevis, the organism responsible for Florida red tide blooms, produces a powerful collection of neurotoxins called brevetoxins. The release of these brevetoxins during a bloom can have substantial impacts on marine life that include massive fish kills and significant mortality events for birds and marine mammals. Large fish kills can occasionally generate hypoxic, or oxygen deficient, zones that amplify the impacts on a broader spectrum of marine life (FWRI 2007, NOAA 2006). The extent to which red tides affect populations of ecologically and economically important fisheries over time and space is poorly known. Human health impacts usually take the form of neurotoxic shellfish poisoning (NSP) and respiratory irritation. Adverse impacts might also result from long-term exposure to brevetoxins but research on the chronic effects of Florida red tide is in its infancy.

Brevetoxins

More than 30 years of research on the toxicity of *K. brevis* has resulted in an increasingly complex picture (Fleming et al. 2005; Baden et al. 2005). Until 1981, only one specific brevetoxin had been identified and scientists thought the lethality of a given red tide bloom was directly related to its cell and toxin concentrations. Since then, a number of additional brevetoxins produced by *K. brevis* have been identified and characterized.



The two pictures shown above are of a patient's lungs before and after a brevenal treatment. The picture on the right reveals more yellow, orange and red areas. These areas reflect better lung function than the corresponding white areas in the picture on the left. Brevenal is natural antagonist to brevetoxins produced by *K. brevis* cells. It was discovered in 2004 and is being evaluated as a possible treatment for cystic fibrosis, a debilitating lung disorder.

Brevetoxins typically affect organisms by opening up the sodium channels of nerve cell membranes and causing the nerve cells to depolarize. This leads to disruptions of muscle function and subsequent respiratory and cardiac distress. Different brevetoxins and their derivatives can vary in their potency, especially when they are modified in a laboratory setting or metabolized by other species in nature. Certain structural features of these derivatives appear to have distinct physiological consequences on neuronal, pulmonary and enzymatic regulatory systems of organisms (Baden et al. 2005). Scientists also recently discovered that *K. brevis* produces brevenal, a natural antagonist that counteracts the effects of the brevetoxin.

It is not known whether the specific combinations of different brevetoxins and the balance between brevetoxins and brevenal in a specific *K. brevis* cell reflect different stages of the cell's life cycle, environmental conditions or both.

The important point is that the toxicity of a given *K. brevis* cell can vary, as can the amount and combination of toxins it releases in its environment. Once released, the potential effects of the brevetoxins can evolve as marine life metabolizes them.

Impacts to Marine Life

Marine life is exposed to brevetoxins by eating them, breathing them or touching them. The toxins can also pass through cell membranes, including the blood-brain barrier and skin tissue (Kemppainen et al. 1991; Apland et al. 1993). Different forms of marine life vary in their reaction to the toxins.

Fish kills are both an early warning sign for humans and a sad hallmark of red tide blooms. Fish kills of up to 100 tons of fish per day have been estimated during active red tides. Fish are exposed to brevetoxins by swimming through blooms and ingesting forms of marine life that have become contaminated with toxins. They are thought to be killed through lack of muscle coordination and paralysis, convulsions and respiratory failure (Kirkpatrick et al. 2004).

Little research has been conducted on the effects that red tide has on specific fish communities. Smith (1975; 1979) documented the decimation and subsequent re-colonization of an offshore reef fish community in the Gulf of Mexico following a single red tide event in 1971. This event appeared to have caused a hypoxic "dead zone" offshore of Tampa Bay and Sarasota and Manatee counties, similar to the dead zone that occurred during the summer of 2005. Smith estimated that 80-90% of the reef fishes were killed by the red tide and that all the species that disappeared from the reefs re-colonized the area within a year. However, Smith believed that several years may be required to re-establish the community to its former structure in terms of relative abundance of each species. Because Smith's work was narrowly focused and targeted only one reef fish community and a single red tide event, much remains to be learned about the ecological effects of red tide on economically and ecologically important fisheries.

Fish mortality often results from acute exposure but many species appear to withstand lower levels of exposure over time and accumulate toxins in their organs. Until recently, it was unclear whether lower trophic species could accumulate and transfer brevetoxins to higher trophic species but a number of mortality events involving manatees and dolphins have confirmed that this can happen. There are, in fact, a variety of potential vectors through which brevetoxins can work their way through the food web. Acute and chronic mortality events are both possible, and significant time lags have been known to occur between the presence of a red tide bloom and a mortality event later linked to a bloom.

Red tide events have been implicated in manatee deaths dating back to 1962 (Steidinger et al. 1998). The most severe episode occurred in 1996 when 149 manatees were killed by brevetoxin exposure. There was no significant lag time that year between the dissipation of the red tide and the last manatee death. Subsequent lung pathologies revealed that the brevetoxins were inhaled (Bossart et al. 1998). The respiratory tract, liver, kidneys and brains of the manatees were primary targets of the brevetoxins and the effects were thought to be chronic rather than acute (Kirkpatrick et al. 2004).

Filter feeding shellfish (clams, oysters and mussels) concentrate the brevetoxins and can cause neurotoxic shellfish poisoning (NSP) in humans. Florida's Department of Agriculture and Consumer Services has a very conservative safety protocol that closes shellfish harvesting areas when red tide cell counts exceed 5,000 cells per liter (fish mortalities are rare below 100,000 cells per liter). A shellfish harvesting area is not reopened until cell counts drop below 5,000 *K. brevis* cells per liter and bioassay tests confirm the shellfish are not toxic. This can take an additional two to six weeks after red tide is gone from a harvest area. To date, there have been no reported cases of NSP attributed to commercially produced shellfish in the presence of a red tide bloom (FDACS 2002).

During a 1982 event there was a lag of approximately three weeks between the dilution of *K. brevis* cell concentrations below levels that should be lethal to manatees and the last manatee death. Necropsies revealed tunicates (a filter-feeding organism that can accumulate toxins) in the manatee stomachs (O'Shea et al. 1991). A 2002 red tide event killed 34 manatees and necropsies suggested that brevetoxin adhering to the surface of seagrass that was eaten by the manatees was the likely vector. In 2004, 107 bottlenose dolphin deaths were reported weeks after a red tide dissipated. A subsequent investigation linked the dolphin mortality event to menhaden (a plankton eating fish) that had accumulated brevetoxins in their organs (Flewelling et al. 2005). Toxic seagrass was again thought to be the primary culprit in the most recent manatee mortality event that also saw another lag between the dissipation of red tide and 27 manatee deaths (Spinner 2007). Considered together, these mortality deaths reveal a number of potential pathways for brevetoxins to work their way through a food web over the period of a month.

Impacts to Human Health

Humans can be exposed to brevetoxins through ingestion of contaminated seafood. Brevetoxins are tasteless, odorless and heat and acid stable. They cannot be easily detected nor removed by food preparation procedures (Baden et al 1997; Kirkpatrick 2004). To date, shellfish are the primary vector, or pathway, for human brevetoxin exposure. Shellfish reported to be associated with neurotoxic shellfish poisoning (NSP) when contaminated with brevetoxins include oysters, clams, scallops and other filter feeders. Thankfully, NSP is considered one of the milder forms of paralytic shellfish poisoning with no known fatalities. Typical NSP symptoms include gastrointestinal symptoms (nausea, diarrhea, and abdominal pain) accompanied by occasional neurological symptoms (headache, vertigo, incoordination). In severe cases respiratory failure has been reported (Kirkpatrick et al. 2004).

Importantly, there have been no reported cases of NSP in Florida resulting from ingestion of commercially harvested shellfish. The Florida Department of Agriculture and Consumer Services maintains a very cautious protocol with respect to closing shellfish fisheries and allowing shellfish products on the market.

To date, all known cases of NSP that have been linked to the brevetoxins from a red tide bloom have involved illegal recreational harvesting activity. There have not been any reported cases of brevetoxin exposure in humans that resulted from ingestion of finfish species. However, the 2004 dolphin mortality event discussed above suggests that some fish species can accumulate brevetoxins in their abdominal organs. Accordingly, recreational fishers should only eat the fillets of fish caught in the vicinity of a red tide bloom and avoid eating any fish that appears to behave unnaturally.

Humans can also be exposed to brevetoxins through inhalation. *K. brevis* cells are fragile organisms that are easily broken open by wave action along the beach. When this happens, the brevetoxins are released and can become aerosolized. When a red tide bloom is near the shoreline, the aerosol of contaminated sea spray will contain toxins that can be carried inland with the prevailing winds. Studies to date show the toxins can travel at least a mile (1.6 km) inland from the shore, and the distance is highly variable and dependent upon environmental conditions, such as wind speed and direction (Kirkpatrick et al. in prep). Inhalation of aerosolized brevetoxins causes respiratory irritation, bronchial constriction, coughing and a burning sensation in the eyes, nose and throat. Less frequent reported symptoms include pulmonary distress, dizziness, tunnel vision and skin rashes (Kirkpatrick et al. 2004). In animal models, many of the respiratory symptoms are greatly reduced by administering common medicines like antihistamines, inhaled steroids, bronchodilators or anticholinergics before exposure. Bronchodilators will reverse most respiratory symptoms after exposure (Abraham et al. 2005).

Asthmatics and other segments of the population with chronic respiratory ailments are especially sensitive to brevetoxins. A series of studies have shown that when people with chronic respiratory problems are exposed to red tide blooms, a greater proportion demonstrate symptoms than those without chronic respiratory ailments (Singer et al. 1998; Abraham and Baden 2001; Fleming et al. 2005, Fleming et al, 2007). The most severe symptoms appear to occur in those with the most serious underlying respiratory ailments (Fleming et al. 2005; Fleming et al. 2007). Symptoms also tend to persist longer in these populations than in persons without any underlying respiratory conditions (Kirkpatrick et al. 2007).

Scientists from Mote Marine Laboratory perform human health studies to determine the effects of red tide on the human population.

Whether inhalation can result in additional neurological or immunological problems is one of the focal points of future research on the health effects of red tide. Laboratory studies of manatees and other animals suggest that these are possibilities, particularly if exposure to red tide is chronic (Benson et al. 1999; Fleming et al. 2001). A recent study of emergency room visits to a Sarasota hospital during the months of September through December in 2001 and 2002 is noteworthy. A large red tide bloom affected the area during Fall 2001 but not 2002. Although the overall number of emergency room visits did not significantly change from one year to the other, there were some suggestive findings. When separated by ZIP code, coastal residents had a 54% increase in emergency room visits during the red tide year with 31%, 44%, 56% and 64% increases in pneumonia, asthma, bronchitis and upper airway disease, respectively (Kirkpatrick et al. 2006). Although the study's findings are limited by its short duration and lack of data on a number of factors that could contribute to the observed variation, it will compel researchers to further investigate the potential for chronic impacts.

Consequences: Economic Impacts

Florida red tides impose significant economic costs in localized areas but the cumulative impacts for an entire coastal region affected by a bloom are difficult to calculate. Estimates of economic impacts are highly inconsistent and heavily dependent upon the assumptions of the analyst. Given the likelihood of displaced economic activity, economists need to better understand how consumers respond to red tide events before they can provide accurate impact assessments. Better data on tourist and recreational activity in the presence of red tide events will be critical for these assessments.

Variation in Estimates

Based upon a subset of HAB outbreaks from 1987-2000, Hoagland and Scatasta (2006) offer an estimate of $82 million for the total economic costs of all HABs that affect the entire United States. The Hoagland and Scatasta study uses the same methodology as Hoagland et al. (2002) and Anderson et al. (2000) which had previously estimated average annual economic losses between 1987 and 1992 at $50 million. With respect to the most recent figure of $82 million, the authors estimate that recreation and tourism impacts amount to an average of $4 million year. Compare this with an estimate by the public relations director of the St. Petersburg/Clearwater Visitors and Area Convention Bureau of $240 million in potential losses for the Tampa region from the 2005 Florida red tide bloom (Moore 2006; NOAA 2007).

So, one economic assessment suggests that the sum total of all economic impacts to the tourism sector across the country averages around $4 million a year, while another claim estimates the economic impacts to be $240 million in a single metropolitan area. The reason for the remarkable variation lies in the different assumptions and methodologies employed in different instances. The authors of the nationwide studies adopted a conservative set of assumptions and focused on a wide range of data sources while the estimate from the St. Petersburg/Clearwater Visitors and Area Convention Bureau results from a simple extrapolation.

Part of the difficulty with calculating economic impacts results from the fact that much of the economic activity affected by a red tide bloom is displaced rather than lost. A family that refrains from eating at a waterfront restaurant when a bloom is active may instead eat at another restaurant further inland. The waterfront restaurant loses some revenue as a result of this decision but the inland restaurant gains a comparable amount. The net impact on the broader community of which the family is a part is probably negligible. If a family changes their vacation plans as a result of a red tide bloom, traveling to Orlando instead of Tampa, then Tampa loses revenue but not the state of Florida. If a family chooses to travel to California instead of Florida because of red tide, then the state of Florida loses revenue but not the country as a whole. The counterintuitive result is that the broader the regional scope of analysis, the less significant some types of economic impacts may appear. Generally speaking, the diversified nature of the U.S. economy mitigates many of types of adverse economic impacts from natural hazards.

With the $240 million estimate cited by the St. Petersburg/Clearwater Visitors and Area Convention Bureau, the public relations director noted that Fort DeSoto beach visitors had increased 6% in 2005 before a red tide bloom began affecting the area. At the end of the year beach visits were only up 2% for the year. Inferring that the red tide bloom resulted in a 4% reduction in beach visitors, the director projected a 4% loss onto the entire metropolitan tourist industry – $6 billion in annual revenues – to arrive at the $240 million figure (Moore 2006). Given the nature of displaced economic activity, this type of extrapolation can be misleading.

National Estimates of Harmful Algal Bloom Impacts

Anderson et al. (2000; see also Hoagland et al. 2002) define economic impacts "to mean lost gross revenues in the relevant product or factor markets, expenditures for environmental monitoring and management or other costs that would not have been incurred in the absence of HABs." They focused on four types of costs: 1) public health; 2) commercial fisheries; 3) recreation and tourism and 4) monitoring and management costs. The authors based their analysis on a survey of experts from different coastal states and a literature review. Some additional data sources were consulted when possible. Public health costs accounted for the largest portion of nationwide HAB impacts (45%), followed by commercial fisheries losses (37%). Recreation/tourism losses (14%) and monitoring and mitigation costs (4%) accounted for the smallest portions. These figures did not include economic multiplier effects, which attempt to account for a ripple effect that occurs when economic losses in one segment of the economy affect the level of activity in others. Ripple effects are highly sensitive to local market structure and the authors of the national estimates decided to forgo using a single economic multiplier and/or calculating separate multipliers for each localized HAB event (Anderson et al. 2000).

The national HAB study authors highlight the fact that their estimates are conservative and they discuss a number of data and methodological challenges. Valid, reliable data that could be compared across cases were difficult to obtain. Few states have conducted economic assessments of HAB impacts or collected data that could be used to generate reliable estimates. Where data were available, extrapolations were often made to compensate for incomplete or underreported measurements. For instance, the authors used a rule of thumb of multiplying the number of reported shellfish poisoning cases by ten to account for the significant underreporting of cases (Hoagland et al. 2002). With respect to commercial fisheries, the authors expressed their desire to obtain measures of lost consumer and producer surpluses in relevant markets due to shifts in supply and demand curves. Most HAB impact studies instead measure and report changes in the gross value of sales, which often fail to accurately reflect welfare changes. Anderson et al. (2000) and Hoagland et al. (2002) also discuss the relevance of the "malleability" of capital and labor or the costs of switching these factors to their next best alternative activity. The less malleable productive factors are the less capable a given economy will be in mitigating the economic losses that result from a red tide bloom.

Florida's economy relies more heavily on its tourism and recreation sectors than other areas of the United States that are affected by harmful algal blooms. The economic losses associated with Florida red tides can climb into the millions of dollars and have an especially significant impact on beach communities.

Estimates of Florida Red Tide Impacts

While the national HAB assessments provide a useful template for analyzing the economic impacts of a variety of HABs, the economic losses associated with Florida red tides are likely to manifest differently from those in other regions. Public health costs, which account for the largest share of impacts in the national assessment, are closely tied to shellfish poisonings. Cases of neurotoxic shellfish poisoning (NSP) from Florida red tide are rarer, sporadic and less severe than other forms of shellfish poisonings around the country. Public health costs therefore represent a much smaller portion of economic costs associated with red tide blooms in assessments done to date. If stronger evidence were to link red tide exposure to chronic respiratory and/or immune system problems, then estimates of public health costs would increase substantially.

Commercial fishery losses associated with *K. brevis* can be significant but are usually localized. Martin (1987) estimates that a 1986 *K. brevis* bloom along the coast of Texas caused the loss of $2 million in oyster production (Martin factored in a multiplier in estimating the total economic impacts to be near $6 million). During the 2002-03 HAB season, the Florida shellfish aquaculture and oyster industries lost $6 million in dockside sales and up to 20% of planted clams (NOAA 2004).

Only a couple of estimates of cleanup costs have been provided in the literature. Habas and Gilbert (1975) estimated the cleanup costs for an extreme 1971 event to be approximately $800,000. Hoagland et al. (2002) cite a personal communication with Sarasota County officials stating that cleanup costs for the county average around $63,000 per year. The authors use this citation as a basis for estimating an annual average of $170,000 in cumulative costs across all Florida counties during a red tide bloom.

Monitoring costs in Southwest Florida are difficult to precisely calculate because monitoring activity is funded as part of an overall research agenda. Red tide research funding has been inconsistent until the turn of the century. For the past five years, it has averaged more than $1 million per year (Heil 2007).

Unlike some of the other regions of the U.S. that have been subjected to HABs, Florida's greatest economic concern lies with its tourism and recreational sectors. Florida's coastal economies generated $402 billion in 2003, or 77% of the state's total economy (Kildow 2006). Tourism generated $63 billion in 2005, with $8.3 billion generated in the recreational fishing sector alone (Hauserman 2006). Nationwide, Florida ranks No. 1 among destinations for Americans who swim, fish, dive and otherwise enjoy the state's many beaches, coastal wetlands and shores. We should thus expect that Florida's economic vulnerability to impacts in the tourism and recreational sectors to be higher than that of other regions. The $240 million estimate of Tampa area losses from the 2005 red tide event may be excessive, but the conservative averages in the national HAB assessments are likely too low.

There have only been a few studies focused on recreation and tourism impacts from Florida red tide. Habas and Gilbert

(1975) estimated the economic damage to the Southwest Florida tourism industry from a 1971 red tide bloom to be approximately $20 million ($95 million in 2006 dollars), with the most significant effects occurring in the hotel, restaurant, amusement and retail sectors. Although outside of Florida, Tester et al. (1988) estimated the recreation and tourism effects from a 1987 *K. brevis* bloom to be $29 million across four coastal counties in North Carolina (the bloom was transported to the East Coast by the Gulf Stream). Hoagland et al. (2002) suggest that some of these losses were likely offset by positive effects in other counties as tourists redirected their vacation activity elsewhere.

©Lucy Keith, Wildlife Trust

The above photo shows residential homes on North Manasota Key along Lemon Bay. The substantial property values along Southwest Florida's coastline are linked to the natural beauty of the area. Recurring red tides are a potential threat to these property values.

Adams et al. (2000) used a time series analysis to measure recreational and tourism impacts to Sarasota and Manatee counties from recent red tide blooms. The study showed a negative impact on beach attendance but no statistically significant economic impacts to the business community. The authors once again speculated that this could have been due to displacement of economic activity to other areas of the county. In a subsequent study (Larkin and Adams 2006), the authors employ a similar method to look at the impacts of red tide on business activity in two smaller ZIP code areas (Fort Walton Beach and Destin). With a more localized scope, the authors were able to find evidence of a 29% to 35% decline in average monthly revenues for restaurant and lodging businesses during months of red tide incidence. These losses amounted to $2.8 million to $3.7 million a month – significant sums for the waterfront business community.

Another potential impact for waterfront businesses and residential communities lies in property values. Anderson et al. (2000) opted against including property values as a type of economic impact in their national study due to the difficulty of calculating these impacts. Waterfront real estate values can be affected by a variety of factors and attributing variation in these values to red tide blooms can be problematic. But the possibility remains that an intense bloom and/or recurring blooms could depress the demand for real estate and adversely impact property values over both the short and long term. Local government revenues derived from property taxes could also be affected.

An important observation from the above discussion is the need for better understanding market behavior before, during, and after the presence of a red tide bloom. Adams et al. (2002) provided some preliminary insights along these lines through a telephone survey of 1,006 individuals living in Manatee and Sarasota Counties. The survey collected demographic data, gauged public awareness and knowledge of Florida red tide and asked questions about the effects of red tide on behavior. The results suggested that recreational activities were significantly affected, but in different ways. Fishing, beach and water activities were the most heavily affected activities and more likely to be postponed rather than redirected. Restaurant, lodging and other forms of retail patronage were less affected. Restaurant patronage was redirected more often than it was delayed but the other forms of patronage were more often postponed. The results suggest that a significant portion of recreational and tourist activity may be redirected but a significant portion might also be postponed indefinitely or lost.

Management Strategies

A NOAA Research Plan for Prevention, Control and Mitigation of HABs (NOAA 2001; Boesch et al. 1997) subdivides HAB management options into three types of activities: prevention, control and mitigation. Preventive measures attempt to stop blooms from occurring, minimize their incidence or limit their extent. Control measures focus on limiting impacts by killing or neutralizing the toxicity of the causative organisms and/or removing the organisms and their toxins from the water column. Mitigation measures seek to limit the impact of the blooms without dealing directly with the causative organisms themselves.

The HAB management terminology might be confusing to those familiar with the mitigation vs. adaptation debate in the context of climate change. In climate change discourse, mitigation strategies denote actions aimed at reducing the extent of climate change, typically pollution control in the form of reduced carbon emissions, while adaptation strategies denote actions to minimize the impacts of climate change (IPCC 2007). HAB prevention measures are thus analogous to climate change mitigation strategies and HAB mitigation measures are analogous to climate change adaptation strategies. There is no conceptual counterpart to HAB control measures on the issue of climate change. To limit the potential confusion, this section will refer to alternative HAB management options by directly referring to the type of activities they involve with the operative HAB management terminology in parentheses.

The key point made in this section is the importance of combining all three types of activities into a comprehensive response strategy. A limited strategy that focuses on only one type of management activity will be insufficient given the complex nutrient dynamics that shape the lifecycle of Florida red tides and the limitations of the current generation of control technologies.

Prevention: Measures to Reduce the Incidence or Extent of Red Tides

Exercising Precaution

There is some skepticism regarding prevention strategies for Florida red tides given their long history, their offshore origins and the uncertainty regarding the nutrient delivery mechanisms that sustain them. Some may view the notion of prevention measures as futile. They may note that Florida red tides have encroached upon Florida long before it was populated and suggest that they will likely continue to do so long into the future. If anthropogenic inputs are assumed to be unrelated to the frequency, intensity or duration of red tide blooms then one might conclude that little can be done in terms of prevention. Even if a less rigid posture is adopted toward the potential links between anthropogenic factors and red tide, some may still resist a strategy incorporating preventive measures on account of uncertainty. This logic suggests that such measures only be considered after clear linkages have been confirmed.

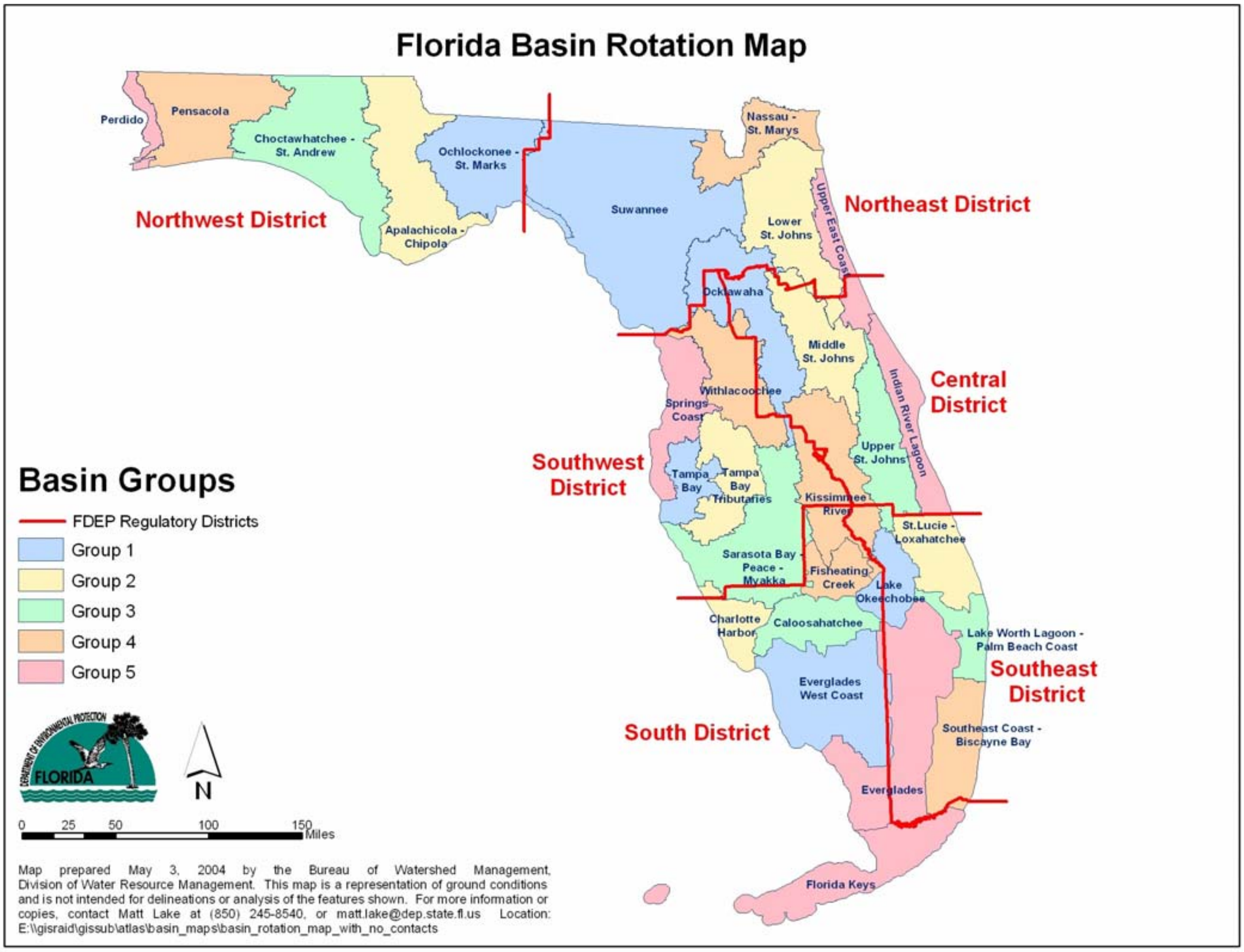
The logic suggesting that preventive measures should be resisted on account of uncertainty is inconsistent with the precautionary principle. As noted earlier, there are reasons to suspect that coastal runoff can exacerbate Florida red tides. More importantly, some of the measures suggested by prevention advocates have important ecological benefits apart from any connection to Florida red tide. Lowering the amount of nutrients that are discharged into Florida's watersheds is a top priority for prevention advocates that engage in red tide debates. Reduced nutrient loads will improve water quality throughout watersheds, in addition to lowering the intensity of terrestrial fluxes when a red tide is in close proximity to the coastline.

Reduced loads may or may not lead to a discernible change in red tide patterns but they will certainly improve the health of Florida's watersheds.

An important issue that prevention advocates need to consider, however, is the modalities of reducing nutrient loads and the most appropriate venues for affecting change. The major sources of water quality impairment in Florida include domestic and industrial wastewater, urban and suburban stormwater, agricultural runoff and hydrological changes. Water quality problems in Florida were historically associated with domestic and industrial point sources but stricter regulatory controls and new wastewater treatment technologies have substantially reduced pollution from these sources. Non point sources now account for most of the water quality problems in the state with urban stormwater and agricultural runoff being the primary concerns. And unlike point source discharges, non point sources are difficult to measure, monitor and control.

Reducing Non Point Source Pollution

The methods of regulating non point sources typically revolve around certification and permitting of best management practices and associated technologies, along with periodic monitoring of water bodies. This departs from the direct measurement and continuous monitoring of discharges that are subject to point source regulations. Permitting for stormwater pollution is conducted through



DEP District	Group 1 Basins	Group 2 Basins	Group 3 Basins	Group 4 Basins	Group 5 Basins
NW	Ochlockonee-St. Marks	Apalachicola-Chipola	Choctawhatchee-St.Andrews Bay	Pensacola Bay	Perdido Bay
NE	Suwannee	Lower St. Johns	N/A	Nassau-St. Marys	Upper East Coast
Central	Ocklawaha	Middle St. Johns	Upper St. Johns	Kissimmee	Indian River Lagoon
SW	Tampa Bay	Tampa Bay Tributaries	Sarasota Bay-Peace-Myakka	Withlacoochee	Springs Coast
S	Everglades West Coast	Charlotte Harbor	Caloosahatchee	Fisheating Creek	Florida Keys
SE	Lake Okeechobee	St.Lucie-Loxahatchee	Lake Worth Lagoon-Palm Beach Coast	Southeast Coast Biscayne Bay	Everglades

This map of Florida illustrates the 29 basin management areas that fall within Florida's six water management districts. The 29 areas are also divided into five groups, represented by different colors that coincide with a rotating schedule of assessment and impairment designation, the assignment of Total Maximum Daily Loads (TMDLs), and the formulation and implementation of Basin Management Action Plans (BMAP)s.

the U.S. Environmental Protection Agency's (EPA) National Pollution Discharge Elimination System (NPDES) stormwater permit program. The program has consisted of two phases. Phase I, initiated in 1990, addresses large and medium municipal storm systems along with a number of categories of industrial activity. Phase II, initiated in 1999, addresses additional sources, including municipal systems not regulated under Phase I and small construction activity disturbing between one and 5 acres (FDEP 2007).

In October 2000, EPA authorized the Florida Department of Environmental Protection (FDEP) to implement the NPDES stormwater permitting program in the State of Florida in all areas except Indian Country lands. As the Pollution Discharge stormwater permitting authority, FDEP is responsible for promulgating rules and issuing permits, managing and reviewing permit applications, and performing compliance and enforcement activities. Florida also has separate stormwater/environmental resource permitting programs and local stormwater/water quality programs, which have their own regulations and permitting requirements (FDEP 2007).

A comprehensive effort is also under way to bring Florida into compliance with the Clean Water Act's Total Maximum Daily Load (TMDL) provisions. In 1998, several Florida environmental groups filed a lawsuit against the U.S. Environmental Protection Agency (EPA) for its failure to enforce the provisions in the Clean Water Act. Total Maximum Daily Loads are the amount of each pollutant a water body can receive without violating water quality standards. Because of the lawsuit, a Consent Decree was issued in 1999 that required the EPA and the FDEP to expedite their assessment of Florida waterways and establish TMDLs in those that are impaired. Florida responded by passing the 1999 Watershed Protection Act requiring the FDEP to establish a priority ranking and schedule for analyzing impaired waters and a methodology for determining which water bodies are impaired. In accordance with the Watershed Protection Act the FDEP has adopted an Impaired Waters Rule and accompanying TMDL Program (Florida Senate 2003). FDEP's five-year report on the Program discusses some significant challenges that FDEP will have to overcome to satisfy the terms of the Consent Decree (FDEP 2005). If FDEP cannot fulfill its obligations by 2012, the EPA may step in and impose more stringent regulations.

The new TMDL Program assigns Florida's 52 watersheds to 29 basins and divides them into five groups that are evenly spread across Florida's six water management districts.

A five-year basin rotation schedule will allow for an assessment of each basin once every five years. The initial assessment is the first of five phases in the TMDL development cycle. It is followed by a second phase of coordinated monitoring that supplements initial assessments and clarifies the status of potentially impaired water bodies. The third phase develops TMDLs in response to an impaired waters designation, the fourth incorporates multiple TMDLs and allocates loads to specific sectors as part of a comprehensive Basin Management Action Plan (BMAP). The fifth phase implements the BMAP.

Initial assessments have been completed for all 29 basins and FDEP is in the process of developing Total Maximum Daily Loads and Basin Management Action Plans. Nutrient load reductions that are mandated through this process will require significant expenditures. Allocating loads will be especially contentious and litigation is expected (FDEP 2005).

If a more definitive link between terrestrial runoff and red tide is established, the most likely regulatory response will take the form of more stringent criteria for NPDES permits, stronger enforcement penalties for noncompliance and Total Maximum Daily Loads that are incorporated into the Basin Management Action Plans. State legislation that addresses red tide specifically is, of course, possible. And local permitting requirements and water quality enhancement programs can go beyond what is required by the state. But beyond requiring supplementary best management practices, most substantive measures would likely need to be harmonized with NPDES permitting requirements and TMDLs that are integrated into BMAPs.

NPDES permitting requirements, Total Maximum Daily Loads and Basin Management Action Plans are critical venues for water quality measures directed at red tides because they are in the process of being developed and they will dictate Florida's water pollution reduction efforts independent of any confirmed linkage to red tide.

Control: Measures to Kill, Neutralize or Remove Red Tide from the Water Column

There are a variety of ways to control, kill and/or remove *K. brevis* cells from the water column. It is easy to do this in a small, contained environment like a laboratory. Controlling red tide blooms at the scales we normally find them in the marine environment is far more challenging. Research is being conducted on a handful of technologies that remain potentially viable for field settings, but the conditions under which these control technologies can be used will be limited in the near term. The most likely applications will be found in intercoastal waterways and canals. Open-water applications pose the most difficult challenges for control technologies, and technological fixes for large-scale blooms would appear to remain a remote possibility over the short-to-medium term.

Five Key Evaluative Criteria

Policymakers need to consider a number of criteria when evaluating potential control technologies that might be deployed against a red tide bloom:

1. Does a considered technology effectively kill, contain or neutralize *K. brevis* cells and/or the brevetoxins they produce? As noted, there is no shortage of physical, chemical and biological materials that can accomplish this.

2. Does the considered technology pose less of an ecological risk than letting the bloom run its course? Destroying *K. brevis* cells is relatively easy. Doing so without harming any other form of marine life is not. Importantly, the ecological risks associated with a given technology should not be considered in isolation. Red tides will significantly alter marine ecosystems and the decision not to intervene with a viable control technology reflects the acceptance of some level of risk. In many of the hypothetical scenarios under which a control technology would be used, the targeted area will have already suffered fish kills and benthic (sea floor) mortality events. The additional ecological risks associated with deploying a control technology under such circumstances are often far less than it would be if we were to consider deploying it in a pristine marine environment. Conversely, it is also possible for a control technology to exacerbate problems by increasing the amount of toxin released into the environment when *K. brevis* cells are destroyed and/or disturbing ecological balances that may or may not be related to the presence of red tide.

3. Is it logistically feasible to deploy a considered technology in a manner that will render it effective? It is this criterion that undermines the viability of a number of potential technologies that work well in laboratory settings. Two logistical factors are especially important. One is the total biomass of an active red tide bloom and the space it covers. When the 2005 red tide bloom was discovered moving in from the bottom of the West Florida Shelf, it already covered an area of 500 square miles, the equivalent of 250,000 football fields. At this size, researchers estimated that it would take a single vessel spraying a chemical agent a full year to cover the corresponding surface area just one time. The other is the importance of deploying the considered technology at sufficient concentrations throughout the water column. Red tide blooms often develop below the surface. Simply treating the surface of the water with a given control agent may prove futile. The depth problem is compounded by ocean currents that may upwell and transport new *K. brevis* cells into an area that has recently been treated. This can occur even after the entire water column in a given area has been cleared. Collectively, these logistical concerns limit the foreseeable applications of most of the control technologies under consideration. Treating small segments of semi-protected areas with modest tidal flows is much more realistic than treating a moderate-to-large bloom in the open water. Larger-scale applications remain a future possibility for some technologies, though, especially when they're combined (e.g. algicidal and/or biotoxin-degrading bacteria in association with clay or another carrier). Logistical obstacles could also conceivably be overcome by deploying a given technology at the appropriate depth shortly after a new bloom initiated. However, we currently have no way of detecting blooms at this very early stage.

4. Economic cost is another criterion that must be considered. The cost of deploying a control technology needs to be considered in relation to the potential economic losses that the control technology is seeking to prevent. Logistical feasibility and cost are often related. Deploying a number of control technologies at a sufficient scale to substantially impact a bloom is often both logistically unfeasible and too costly to seriously consider. Some deployments of control technologies may be logistically possible but still too costly. While policymakers should seriously consider spending $100,000 to prevent $1 million in damages, spending $1 million to protect against $100,000 in damages makes little sense. When considering a range of potentially viable control technology options, cost will become a significant factor in determining the most appropriate control technology for deployment.

5. The final criterion that warrants consideration is public perception. While related to actual ecological risks and economic costs, public perception toward the use of a particular control technology remains a factor that affects policy decisions. Public resistance can generate a number of social and political ramifications that are distinct from economic and environmental costs. These ramifications no doubt already factor into policy decisions — as well they should.

Flocculation

Flocculation refers to a process by which a substance is added to a solution to create a "floc" that removes fine particulates by binding with them and causing them to clump together. With respect to red tide blooms, the targeted particulates are *K. brevis* cells and toxins. Although most HAB research has focused on clay flocculation, a variety of substances can serve as flocculants. Recent research has begun to explore the viability of using sand, shells, sediment and other naturally occurring substances as flocculants.

Clay flocculation can be considered as one of the only HAB control technologies with a partially successful track record in the marine environment. In Asia, it has been used with some measure of success to protect aquaculture facilities from HABs (Maruyama et al. 1987; Shirota 1989; Choi et al. 1999). Treatment of an area affected by a bloom involves spraying the area with clay slurry from a boat. As the slurry floats down through the water column it binds with the algae cells, clumps together and drifts down to the sea bottom.

Ideally, the cells become trapped on the bottom and die. Dosage and water flow are critical issues, however. If the slurry concentration is too high, it may rupture the cells while they remain suspended in the water column causing the release of toxins. Higher dosages may also pose greater risks to other forms of marine life that have not already been killed by a bloom. If the slurry concentration is too low, it may fail to remove many cells from the water column. Moderate levels of water flow appear to be conducive to flocculation dynamics, but they can also increase the rates of re-suspension of cells away from the sea floor. Lower flow rates may reduce flocculation rates but help keep the floc on the sea bottom (Sengco 2007).

Research targeting *K. brevis* cells has demonstrated the technology's potential under controlled conditions. The results suggest that treatments during periods with minimal to modest tidal flows may be effective in highly targeted areas. Moderate to strong tidal flows and/or high winds in the immediate wake of a treatment can re-suspend the cells off the sea floor and impede the efficacy of the treatment. Benthic impacts resulting from dead *K. brevis* cells and their associated toxins can vary but they do not appear extensive so long as there is adequate mixing during a complete tidal cycle. In fact, research results suggest that some benthic filter feeders may benefit from having the brevetoxins trapped in the sediment as opposed to suspended in the water column (Sengco and Anderson 2004; Archambault et al. 2004; Haubois et al. 2005).

Phosphatic clay is one of the most effective flocculants but there are concerns with nutrients, heavy metals and radionuclides in Florida's phosphatic clay. Alternative clays from outside of Florida have been considered but transport costs are a major concern (Anderson et al. 2004). New research is exploring the viability of using sand and other sediments from dredging activities as well as a chitin composite of crustacean shells as flocculants (Sengco 2007).

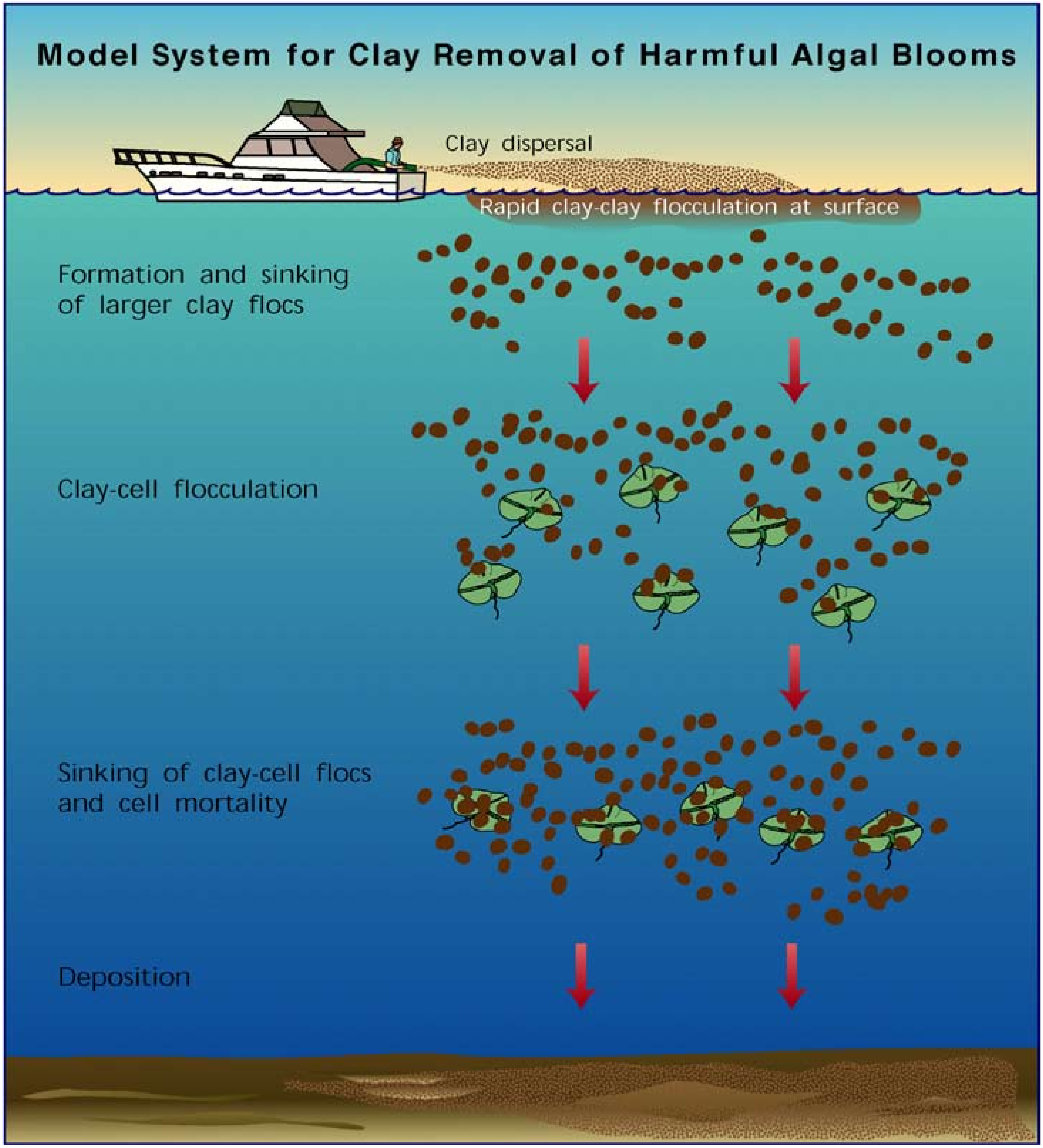
Flocculation remains a potentially viable weapon against Florida red tide, but its applications may be limited to small-scale treatments and its efficacy will vary with environmental conditions. Medium-to-large scale applications remain possible over the long term, perhaps in conjunction with chemical or biological agents. Flocculation must also overcome lingering challenges with regard to ecological risks, economic costs and public perception.

Ozone

Ozone is a molecule consisting of three oxygen atoms. It must be maintained at low temperature and high pressure and it becomes highly unstable as temperatures rise and fall. It has a very high oxidation potential. Ozone is toxic but dissipates very rapidly and does not remain in the water. Many municipal drinking water systems kill bacteria with ozone instead of the more common chlorine. Ozone can be produced on demand with electricity and is often a cost-effective method of treating water. It does not require transportation and storage of hazardous chemicals and once it has decayed it leaves no taste or odor in drinking water.

Ozone offers a number of potential advantages as a control technology for Florida red tide. Unlike most other control technologies, it will destroy brevetoxins in addition to killing or inhibiting *K. brevis* cells (Pierce et al. 2003; Pierce et al. 2004). It will also oxidize decaying fish and reoxygenate waters than have lost oxygen and become anoxic as a result of a bloom. Its major disadvantage is its toxicity. Although the toxicity only lasts for seconds after release into the water column, high concentrations of ozone will kill indiscriminately and the possibility of degassing into the atmosphere can pose a serious danger to humans conducting the treatment if strict protocols aren't followed (Schneider et al. 2003).

Ozone stands out among control technologies in terms of efficacy and cost in small-scale applications. Logistical considerations limit the scope of ozone treatments beyond small-scale targets. Its ecological and occupational risks are short-lived but significant.



This diagram depicts the process of flocculation. A flocculant (typically clay) is dispersed from the back of a vessel in the form of a slurry. As the slurry sinks through the water column, it binds with *K.brevis* cells and traps them on the bottom where they die.

Other Chemical and Biological Agents

One of the only attempts to control a red tide bloom in open waters took place in September and October of 1957. One-hundred-and-five tons of copper sulfate was dispersed along a 32 mile stretch of the west Florida coast (from Anclote Key to Pass-a-Grille Beach), approximately three miles offshore. The total area covered was approximately 16 miles. The copper was initially distributed from burlap sacks dragged behind ships but this proved ineffective for covering large areas, so crop dusting planes were used. The effects were immediate as cell concentrations dropped from 10 million cells per liter to zero across most of treated area. Within two weeks, however, bloom concentrations returned to high levels in two of five monitored areas. Collateral damage to the ecosystem from the copper treatment was not monitored. In addition to its potential for ecological damage and limited efficacy, the cost of the copper sulfate treatment has since discouraged decision makers from seriously considering it as a viable control method (Rounsefell and Evans 1958; Sengco, in prep).

A number of additional tests have since been conducted to find chemicals that could kill or inhibit *K. brevis*. Marvin and Proctor (1964) tested more than 4,000 compounds and found none to be effective within acceptable levels of cost and/or ecological risk. Research continues on potentially viable chemical agents but issues of cost, efficacy, collateral damage and the logistical challenges of dispersing the chemicals at an appropriate concentration throughout the water column have remained daunting.

In addition to chemical agents, researchers are experimenting with algicidal bacteria as potential control agents for *K. brevis*. These bacteria are ubiquitous on the West Florida shelf and they can influence the growth and decline of blooms through direct or indirect interactions. The bacteria need not kill *K. brevis* to be effective, but may render them vulnerable to predation from other micro-organisms (Sengco, pers. comm. March 2007). Combining algicidal bacteria with other chemical compounds or flocculants is possible, and precedent does exist for similar approaches in the form of bioremediation of oil spills, that is using bacteria in combination with other compounds to clean up the spills. The major challenges for biological agents are the same as for chemical agents. Can sufficient amounts of bacteria be cultured to substantially impact a bloom and at what cost? If artificial production requirements are eased by the bacteria's ability to grow in the presence of a bloom, what will happen to the large bacteria population after the bloom subsides and how will it affect the balance of the larger bacterial community in the broader ecosystem? These questions remain at the forefront of research on biological agents to control red tide.

Mitigation: Measures to Reduce the Impacts of Red Tide

HAB mitigation strategies focus on limiting the impacts of HABs without addressing the causative organism, *K. brevis,* directly. A variety of activities can be considered within this category, including efforts to learn more about the natural and human dimensions of Florida red tides and efforts to effectively communicate that knowledge as a means of reducing harmful impacts.

Improved Monitoring Capacity

Efforts to detect, monitor, track and predict red tides are an integral component of a sound mitigation strategy. Preparation for - and responses to - red tide blooms become more difficult when detection provides little warning, when monitoring is inconsistent and when prediction models provide little guidance. These efforts can also play an important role in prevention and control strategies. The earlier red tide blooms are detected and the longer they are tracked, the easier it will be to determine the conditions under which different nutrient sources become relevant in the development and maintenance of a bloom. This will inform prevention strategies. Early detection and accurate projections of bloom movement are also likely to be vital to the efficacy of most control technologies.

Initiatives to better detect, monitor, track and predict red tides are ongoing at the state, regional and federal levels. At the state level, the Florida Fish and Wildlife Research Institute (FWRI) engages in an ongoing monitoring and sampling program with weekly updates made available through its website.

At the regional level, an *Action Plan for Harmful Algal Blooms and the Gulf of Mexico Coastal Observing System* was recently developed in conjunction with a regional workshop on the topic (NOAA/CSC 2004). The workshop recommended that a Harmful Algal Blooms Observing System (HABSOS) be developed and integrated into existing observing systems including the Integrated Ocean Observing System (IOOS) and the Gulf of Mexico Coastal Observing System (GCOOS). Although initially focused on the Gulf of Mexico, NOAA officials envision that HABSOS will be expanded into a national program. The purpose of the program will be to provide updates on the location of existing blooms, early alerts to new blooms, forecasts of bloom movements and probabilities that new blooms would occur. HABSOS remains under development.

An existing tool that already performs some of these functions is the NOAA HAB Bulletin. Currently operational in the Gulf of Mexico, the HAB Bulletin is proving useful for Florida's state managers in making decisions about when and where to monitor the hundreds of miles of coastline and associated shellfish beds. As new technologies and modeling tools become available, the HAB Bulletin should improve.

The importance of robust monitoring capacity for an effective mitigation strategy is not lost on Florida's foremost authorities on oceans and coastal management. The Florida Oceans & Coastal Resources Council continues to list capacity building measures for observing systems as a high priority in its Annual Science Research Plan (Florida Oceans & Coastal Resources Council 2007).

Human Dimensions Research

A far greater amount of research effort has been directed toward the physical dimensions of Florida red tides when compared to efforts that focus on its human dimensions. This asymmetry reflects both a dearth of social scientists working on HABs and a poor track record of integrating natural and social science research agendas on a variety of marine environment problems that include HABs. These deficiencies can hamper the ability to effectively mitigate HAB impacts because effective mitigation strategies often entail managing human behavior more so than the HABs themselves.

The above picture shows a Slocum Glider, also referred to as an Autonomous Underwater Vehicle (AUV). The glider is designed to monitor area waters at varying depths in order to detect harmful algal blooms and the conditions under which they form.

The significance of human dimensions research has recently been recognized by the HAB research community in its *Human Dimensions Research Strategy for Harmful Algal Blooms* (Bauer 2006 or HARR-HD). HARR-HD outlines six areas of human dimensions research with accompanying recommendations. Two of the research areas outlined in HARR-HD are discussed in earlier sections of this report: socioeconomic impacts and human health impacts. A third, recreational and drinking water impacts are less relevant with Florida red tides but can be considered in the context of water quality. The remaining three areas are risk communication, interagency coordination and public education and outreach.

Risk communication research is critical for educating and informing the public in a manner that allows it to understand the probability of a HAB event, trust the message and respond in ways that help them reduce their vulnerability and promote their recovery. Key areas of risk communication include determinates of organizational trust, risk perceptions, social amplification of risk, media engagement and message development and design. Institutional research, including interagency coordination, is critical for understanding institutional incentives, gaps and overlaps in governance authority and opportunities for reform. In the presence of a red tide bloom, the public wants to know who's in charge and what can be done to alleviate the problem. Can emergency response strategies be developed that are akin to those in place for other natural hazards? Can local governments and state agencies improve their coordination efforts during red tide blooms? Do laws need to be changed in order to improve our overall response strategy? The next section offers some preliminary observations with respect to governance issues but more thorough assessments and analyses are needed.

Public Education and Outreach

Public education and outreach is perhaps the most vital component of an effective mitigation strategy. Southwest Florida benefits from a combination of active research and stakeholder organizations. Mote Marine Laboratory, the Florida Fish and Wildlife Research Institute (FWRI) and the Florida Department of Health have partnered with a grassroots network known as START (Solutions To Avoid Red Tide) to form the Red Tide Alliance. The Alliance seeks to educate the public about the effects of the Florida red tide and other harmful algal blooms. Regional and local chapters of the Sierra Club are also very active in their public education and advocacy campaigns that target Florida red tide. Although these and a handful of other organizations disseminate red tide information in the Southwest Florida region, coordination and consistency are sometimes lacking. And few have adequate feedback mechanisms that can ascertain the effectiveness of their respective education and outreach activities.

While differing priorities and perspectives may preclude a sweeping consensus on all aspects of red tide research, management and policy preferences, greater effort can be made to broaden collaboration among the range of organizations and stakeholder groups that are active on the issue of red tide, especially with respect to public education. These efforts should include Chambers of Commerce and Tourist and Visitor's Bureaus in addition to environmental advocacy groups. Future public education and outreach initiatives should be designed in a manner that builds upon other areas of human dimensions research including institutional analysis and risk communication. These initiatives should also include a variety of ongoing surveys to assess program effectiveness.

Governance Issues

The Regulatory Framework for Florida Red Tide

There is a complex array of laws and organizations operating at federal, state and local levels that pertain or could pertain to Florida red tide. Interplay occurs "vertically" between different levels of government and "horizontally" across different physical domains and issue areas. Different physical domains include marine vs. terrestrial areas and areas with national park and/or wetlands designations. Different issues can include those involving wildlife, environment, water provision, health and a variety of economic activities like agriculture, fisheries, mining, etc.

Federal Governance

The most relevant organizations at the federal level include the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the National Institutes of Environmental Health Sciences (NIEHS), the Army Corps of Engineers (ACE), the National Centers for Disease Control and Prevention (CDC), the National Park Service (NPS) and the National Science Foundation (NSF).

The respective roles of these agencies vis-à-vis their state counterparts are collaborative in many areas, clearly demarcated in some and contested in others. Collaboration is most notable with respect to research. The federal government plays a vital role in the provision of research funding and infrastructure that are critical to effective management strategies. NOAA, NIEHS, EPA and NSF provide varying degrees of funding for HAB research programs working closely with state agencies. An important piece of legislation for research funding is the Coastal Zone Management Act. The Management Act authorizes a variety of programs and initiatives to encourage coastal states to develop and implement coastal zone management plans. Another is the Harmful Algal Bloom and Hypoxia Research and Control Act. Enacted in 1998, this Act recognized that many of our nation's coastal areas were suffering from HABs and hypoxia each year, threatening both coastal ecosystems and human health. The Act was reauthorized in 2004 to provide an updated research framework for addressing HABs that requires stronger consultation with local resource managers (HARRNESS 2005).

Demarcation of federal authority is most salient with respect to the spatial dimension of red tide issues. The federal government maintains authority over activities in U.S. waters beyond nine miles from the Gulf of Mexico coastline of U.S. states. Deployment of red tide control technologies in federal waters would likely require an National Pollution Discharge Elimination System permit from the EPA. Activities undertaken in areas designated as national parks fall under the jurisdiction of the National Park Service. Construction activities undertaken in areas designated as wetlands require permits from the Army Corps. The Army Corps and EPA also maintain a degree of authority over activities affecting navigable waters, although the definition of "navigable" remains subject to judicial interpretation (Meltz and Copeland 2007).

Water governance is perhaps the most contested area with respect to the parameters of federal vs. state government authority on a red tide-related issue. Water governance can be thought to include both water provision and water pollution. The previous discussion of preventive measures in the context of Florida's Total Maximum Daily Load program, EPA oversight and the Clean Water Act offer a glimpse into the vertical interplay between state and federal authorities on this issue.

State Governance

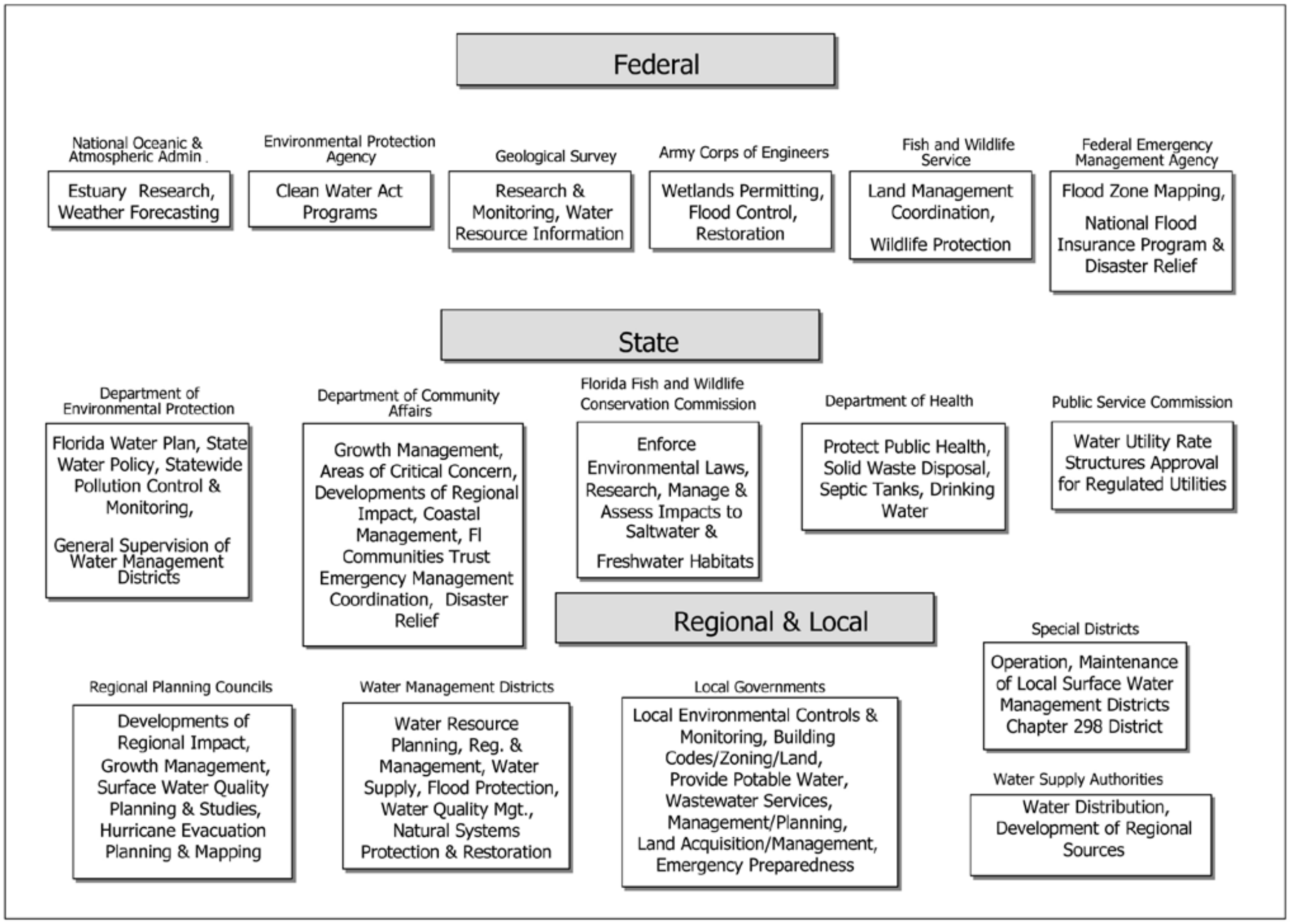
Some of the relevant organizations within Florida that operate on the state and regional levels include the Florida Fish and Wildlife Conservation Commission (FWC) and its Fish and Wildlife Research Institute (FWRI), the Florida Department of Environmental Protection (FDEP) and its five Water Management Districts, the Division of Environmental Health within the Florida Department of Health (FDOH) and the Florida Department of Agriculture and Consumer Services (FDACS).

FWRI oversees most of Florida's red tide research programs and provides the most centralized source of information on red tide queries as it acts as the State's "first responder" to reported blooms. The FWRI can be considered the counterpart to and/or research partner for a number of federal agencies that support red tide research programs.

Another centralized entity that could offer additional governance and oversight of red tide-related activities is the Florida Harmful Algal Boom Task Force. The task force will be discussed in the next section.

The FDEP can best be considered Florida's counterpart to the EPA. As discussed in the section on preventive measures, the FDEP is currently involved in a massive effort to assess

©FDEP 2006



The above chart shows the substantial number of organizations that interact with the Florida Department of Environmental Protection (FDEP) on water management issues. The regulatory frameworks (laws and governing authorities) that are potentially relevant Florida red tides can be highly complex.

the impairment status of Florida's waterways, develop a Total Maximum Daily Load Program and implement the program through a suite of Basin Management Action Plans. FDEP is also responsible for issuing environmental resource permits in conjunction with water use and wetlands activities.

Many of FDEPs water governance responsibilities are carried out through its five Water Management Districts. Chapter 373 of the Florida Statutes gives the Florida Department of Environmental Protection "general supervisory authority" over the districts and directs the Department to delegate water resources programs to them where possible. Pursuant to these delegations, the districts are authorized to administer flood protection programs and to perform technical investigations into water resources. The districts are also authorized to develop water management plans for water shortages in times of drought and to acquire and manage lands for water management purposes under the Save Our Rivers program. Regulatory programs delegated to the districts include programs to manage the use of water, aquifer recharge, well construction and surface water management. Although district charters were changed in the 1970s to include issues of water quality, only a small portion of their budgets are allocated to quality issues and FDEP retains authority over the TMDL program. The FDEP is also responsible for implementing the State Water Resource Plan and has the power to implement programs to attempt to mitigate problems with water resources, such as red tide. FDEP engages with numerous state and local organizations in carrying out its water governance mandates.

The Florida Department of Health's Division of Environmental Health is mandated by Chapter 381, among other statutes, to conduct an environmental health program that will "detect and prevent disease caused by natural and man-made factors in the environment." This is different than the FDEP mandate in that it focuses directly on the health of the environment and the public, giving this organization the ability to address the wider consequences of red tide in terms of human health. This mandate can conflict with or overlap that of the FDEP or other agencies. In addition, the Division of Health does not possess the ability to effectively monitor and regulate those whose actions are potential factors in the exacerbation of red tide and other water problems.

©Sarasota County

The above photo shows an example of a "no-mow" zone along a seawall in Sarasota County. This is an example of a bast-management practice for homeowners who live along waterways. Floridians are discussing the merits of mandating such practices through local government ordinances.

The Florida Department of Agriculture and Consumer Services (FDACS) has crosscutting authority over a number of issues that pertain or could pertain to red tide. FDACS plays a key role in the TMDL program with respect to the development of best management practices for agriculture, it is charged with the enforcement and administration of Florida's Commercial Fertilizer Law, and it has responsibility for maintaining the safety protocols for the State's aquaculture shellfish harvesting program.

In addition to the statutes governing the environment and health of Florida's waterways, there are a multitude of statutes that address the economic sectors most commonly identified as affecting water quality in Florida. Various statutes, task forces and commissions address mining, agribusiness, development, fertilizer manufacturing and distribution, roadway development and petrochemical runoff, sewage treatment and several other areas that are relevant to coastal pollution.

Local Governance

While the state and federal government continue to sort through their respective governance and oversight responsibilities, it is local communities that most often bear the brunt of a given bloom's impacts. Cleanup of fish kills is the responsibility of local governments but this appears to be done on an ad hoc basis independent of local laws and ordinances. It does not appear that local governments in Southwest Florida have emergency response plans for red tides that are comparable to those for hurricanes and other natural hazards, but this is something that local governments could consider. Advance planning for timely cleanup of fish kills, centralized information sources for bloom forecasts and beach advisories and concerted efforts to provide tourist and recreational options in lieu of activities affected by red tide blooms can all help to mitigate the impacts of a red tide bloom.

Local governments have also become active in terms of preventive measures. A recent Sarasota County Fertilizer and Landscape Management Code requires a set of best management practices for various aspects of fertilizer use within the county. Sanibel Island has also passed a similar ordinance. Industry interest groups have attempted to preempt these and future ordinances by lobbying for legislation that would establish statewide standards for fertilizer use (Whittle 2007).

While there may be specific elements of proposed ordinances that will require statewide harmonization, the notion of uniform ordinance for the entire state or a regulatory ceiling for local governments seems unwise and inconsistent with FDEP's watershed management strategy. FDEP is developing standards and programs that are tailored to individual basins and watersheds. The level of regulation for non-point source pollutants will vary from basin to basin and from watershed to watershed. A model fertilizer ordinance could prove useful in establishing a benchmark for local governments to consider, but it shouldn't be embedded in legislation that inhibits the flexibility of FDEP's watershed management approach or that prevents local communities from tailoring local ordinances to their specific needs.

The Florida Harmful Algal Bloom Task Force

The Florida Harmful Algal Bloom Task Force was first established in 1997 as an ad hoc advisory body to address harmful algal bloom (HAB) issues in Florida waters. Members included representatives from government, universities and the public and private sectors. In 1999, the Task Force was legislatively authorized via statutes Ch. 370.06092, F.S. and Ch. 370.06093, F.S., and charged with: 1) reviewing the status and adequacy of information for monitoring physical, chemical, biological, economic and public health factors affecting harmful algal blooms in Florida; 2) developing research and monitoring priorities that included detection, prediction, mitigation and control; 3) developing recommendations that could be implemented by state and local governments and 4) developing recommendations to the Florida Marine Research Institute (now the Florida Fish and Wildlife Research Institute). The legislation also expressed its intent for the Task Force to develop its priorities and recommendations with a view toward complementing the work being carried out by the cooperative federal-state program known as Ecology and Oceanography of Harmful Algal Blooms (ECOHAB-Florida). Continuation of the Task Force after the completion of its reporting requirements was left to the discretion of FWRI.

The Task Force commissioned a Technical Advisory Group that prepared its lone report in 1999 (Steidinger et al. 1999). Although many important research findings can be traced back to the recommendations of this initial report, there have been a number of significant HAB events, emerging issues and advances in HAB research since it was released. The FWRI announced its intentions to revisit and update the Task Force's report in Fiscal Year 2006-07 but this has yet to be done. The need to perform the functions outlined in the Florida HAB Task Force's legislative mandate is as strong today as it was when it was established. Funding and reconvening this body could allow for a number of effective governance functions to be performed. However, some observations are warranted:

1. Greater consideration should be given to the relationship between the functions of the Florida HAB Task Force and the most appropriate structure for fulfilling those functions. Important governance functions that the Task Force could fulfill include: 1) organizing and prioritizing the scientific questions and management concerns pertaining to red tide and other harmful algal blooms in Florida; 2) summarizing the best available science that can address these questions and concerns; 3) identifying the resources needed to address unanswered questions or concerns; and 4) providing mechanisms for programmatic assessment, external review and mediation of scientific disputes. The language of the 1999 legislative mandate speaks to these functions in varying degrees.

2. Although the Florida HAB Task Force had nominal representation from government, universities and both the public and private sectors, the overwhelming majority of Task Force members were representatives of state regulatory agencies. The Technical Advisory Group that worked in concert with the Task Force was comprised of scientists, most from the same regulatory agencies represented on the Task Force with a few others from independent research laboratories and academia. This arrangement is well suited for enhancing communication and collaboration between regulators and researchers, but it only allows for modest input from stakeholder groups and local governments. Consideration should be given to reconstituting the Task Force in a manner that provides for a greater balance between state and local policymakers as well as a broader range of stakeholders that are affected by HABs in Florida.

3. Consideration should be given to establishing an External Review Committee that is distinct from the Technical Advisory Committee. Members of the External Review Committee should have minimal ties to the Florida HAB research community and minimal ties to Florida stakeholder groups. In addition to assessing the state's research and management programs, the review committee could be used to mediate scientific disputes that may arise among members of the Technical Advisory Group and/or between this group and other HAB researchers that are critical of a particular area of work. If the Florida HAB Task Force is not reconstituted in a manner that includes an External Review Committee then consideration should be given to creating or commissioning a separate body to perform this function.

External Review

The frequency and severity of red tide outbreaks over the past decade has put a considerable amount of stress on our Southwest Florida communities. Frustration with red tide has strained community relationships with state regulatory agencies and red tide researchers. The community wants to be assured that existing answers to their most pressing questions about red tide represent accurate depictions of the best available science and that researchers are doing everything they can to reduce the uncertainties in their answers. Regardless of how or why trust breaks down, when it does, it becomes very difficult for the people most directly involved in the red tide research program to provide the necessary assurances. Under such circumstances, an external review of the program conducted by qualified experts that are unaffiliated with it could prove invaluable. It could help mediate some of the most contentious scientific disputes, endorse program areas that are performing well, outline measures for improvement and help to restore trust with disaffected stakeholders.

To a limited degree, this Marine Policy Institute assessment attempts to make a constructive contribution along these lines. But the Institute currently lacks the range and depth of expertise necessary to definitively resolve the most contentious scientific disputes and it lacks the formal independence necessary to function as an impartial external review body. The Marine Policy Institute thus recommends that a separate mechanism be developed to provide this function for Florida's HAB research and management programs.

The previous section discusses the possibility of redesigning the Florida Harmful Algal Bloom Task Force in a manner that provides for external reviews. Two additional models for conducting external reviews can be found in the Florida Bay Science Oversight Panel and the Maryland Blue Ribbon Citizens *Pfiesteria* Action Commission.

Responding to mounting concerns over the role of nutrient loads in the deterioration of Florida Bay, the U.S. Department of Interior commissioned an independent scientific assessment in 1993 (Boesch et al. 1993). After the initial assessment, a Florida Bay Science Oversight Panel was established as an independent peer-review group charged with providing regular, broad, technical and management review of the Interagency Florida Bay Science Program. It continues to review agency plans, strategies for program development, scientific quality of research, modeling and monitoring and research results (NOAA 2000).

Maryland's Blue Ribbon Citizens *Pfiesteria* Action Commission was appointed in 1997 by then-Governor Parris Glendening in response to an apparent outbreak of a harmful alga known as *Pfiesteria piscicidia* in Chesapeake Bay. The commission was charged with making recommendations for managing the risks associated with *Pfiesteria* and minimizing the likelihood of future outbreaks. The commission conducted intensive investigations into the myriad scientific and public policy aspects of the *Pfieisteria* issue. Many scientific briefings were held to inform legislative committees, government committees, the public and the scientific community. The political momentum generated by the Commission's findings was largely responsible for Water Quality Improvement Act of 1998 (Boesch 1997; Maginen 2001). Despite its regulatory impact, concerns have since been expressed about the interplay between science and politics in the Maryland case (Belousek 2004).

Discussions with individuals involved with these external review mechanisms suggest that the Florida Bay model is perceived as less politicized while the Citizens Pfiesteria Action Commission is perceived as having greater impact on the regulatory process. The Marine Policy Institute does not endorse a particular model for external review, but suggests that further discussion of the strengths and weaknesses associated with different models take place. The MPI also recommends the following guidelines for conducting external review.

1. Define the mandate and parameters for an external review team before selecting external reviewers;

2. Use area of expertise, scientific qualifications and impartiality (minimal ties to Florida research organizations and stakeholder groups) as primary criteria for selecting external reviewers;

3. Allow the selection process to be administered by an organization or individual that is trusted by a broad range of scientists and stakeholders;

4. Allow for stakeholder input on prospective candidates prior to final selection.

An external review does not guarantee that the scientific disputes will be resolved or that all stakeholder groups will be happy with the outcomes. In the absence of such a review, however, efforts to politicize red tide research will likely persist as long as red tides continue. The absence of a formal review process will also encourage disaffected stakeholders to attempt their own external reviews in a manner that is likely to neglect the guidelines outlined here.

Conclusion

Scientific uncertainty regarding the potential linkages between coastal pollution and Florida red tide should not detract from progressing with agendas that address both. Florida needs to reduce coastal pollution — in the form of nutrient loads to Florida watersheds — for reasons other than red tide. And it needs to deploy a comprehensive management strategy for combating red tides that goes beyond reducing nutrient loads.

Decades of research have contributed to an impressive body of knowledge on K. brevis, its life cycle, and the conditions that lead to red tide blooms on the West Florida Shelf. Given what we know, it will be very difficult to prevent the periodic recurrence of Florida red tides.

But there are actions that we can take to improve the way that we deal with them.

- We can take precautionary measures that reduce potential human contributions to red tides with the hope of easing the intensity and duration of blooms.

- We can push forward with field studies with existing control technologies that have the potential for removing or destroying K. brevis cells in small areas under specific conditions.

- We can explore the potential for new technologies that may be able to expand the range and conditions under which they can be effective.

- We can undertake a variety of activities that will improve our ability to predict, monitor, and track blooms and to better prepare, respond and recover from them.

- We can improve the oversight of our research and management of Florida red tide — and harmful algal blooms more generally — by funding and improving upon existing governance mechanisms.

Collectively, these actions can help reduce the impact that Florida red tides have on our coastal communities and improve our quality of life.

Appendix: Q&A

The following set of questions and answers synthesizes and integrates the most pertinent research findings and policy recommendations from this report.

Are Florida red tides getting worse?

Possibly. Harmful algal blooms (HABs) appear to be getting worse throughout the world. Some of the forcing factors believed to play a role in the worldwide trend are increased nutrient enrichment resulting from population growth and land use practices and increased water temperatures due to global climate change. Although the general trend appears to be worsening, trends for specific HABs can embody more uncertainty. This is particularly true for offshore HABs such as *Karenia brevis*, the organism that causes Florida red tides. Southwest Florida has endured red tide blooms on a near-annual basis over the past two decades, and the 2005 bloom was one of the most severe on record. However, Florida red tide blooms of similar intensity and duration have been confirmed as far back as 1948-49, and anecdotal evidence suggests that severe blooms have scourged the region for hundreds, if not thousands of years. There is broad consensus that Florida red tides have been especially active in recent years, but putting this decade into historical perspective is extremely difficult due to a lack of data suitable for determining historical trends.

Can coastal pollution exacerbate Florida red tides?

Probably. The recipe for Florida red tides is complex. The relative importance of different ingredients - nutrient sources and other environmental factors - varies over the different stages of a bloom and it is possible that the specific recipe responsible for red tides varies from bloom to bloom. Terrestrial nutrient fluxes are one of many ingredients that can contribute to a red tide bloom, and coastal pollution exacerbates these fluxes. Most scientists agree that red tide blooms initiate offshore before being transported inshore by wind and ocean currents. They believe coastal runoff is unlikely to affect the early stages of a bloom, but when a bloom moves inshore, they acknowledge that runoff can play a role in intensifying or prolonging a bloom. Assessing the relative importance of terrestrial nutrient sources, including coastal pollution, remains a top research priority.

What impacts do Florida red tides have on marine life and human health?

Karenia brevis, the organism responsible for Florida red tide blooms, produces a powerful collection of neurotoxins called brevetoxins. The release of these brevetoxins can cause massive fish kills and significant mortality events for sea birds and marine mammals. Large fish kills can occasionally generate hypoxic zones, or areas of low oxygen, that can kill even more marine life. The extent to which red tides affect populations of ecologically and economically important fisheries over time and space is poorly known. Human health impacts usually take the form of neurotoxic shellfish poisoning (NSP) and respiratory irritation. Adverse impacts could also result from long-term exposure to brevetoxins, but research on such chronic effects of Florida red tide in humans is in its infancy.

What impacts do Florida red tides have on the economy?

Florida red tides impose significant economic costs in localized areas, but the cumulative impacts for an entire coastal region affected by a bloom are difficult to calculate. Existing estimates are highly inconsistent and heavily dependent upon the assumptions of the analysts. Given the likelihood of displaced economic activity, economists need to better understand how consumers respond to red tide events before they can provide accurate impact assessments. Better data on tourist, recreational and real estate activity in the presence and absence of red tides will be critical for future assessments in Florida.

What management options exist for responding to Florida red tides?

There are three types of management options for dealing with Florida red tides:

1. Measures that reduce potential human contributions to red tide (preventive measures);
2. Measures to control or eliminate red tide when it occurs (control measures);
3. Measures to reduce the impacts of red tide when it occurs (mitigation measures).

Effective management strategies should incorporate all three options. Excess nutrients in our watersheds give rise to a variety of problems that we need to avoid. A precautionary approach to Florida red tides that incorporates the reduction of nutrient loads as a part of a general nutrient management strategy will yield benefits that go far beyond impacts on red tide. Research on control technologies should continue. Given the limited applications for the most viable technologies projected over the short term, the research portfolio should remain diversified. A more substantial effort should also be made to improve efforts to mitigate red tide's impacts. Mitigation measures should include a robust program on monitoring, detection and forecasting, but it should also include a robust human dimensions research agenda and an aggressive education and outreach program. This would include projects that measure public perception and knowledge about red tide, projects that measure economic activity before, during and after blooms and projects that improve upon interagency coordination and emergency response and recovery plans.

What regulatory mechanisms exist for reducing coastal pollution?

There is a widespread consensus that Florida needs to reduce the amount of non-point source pollution that makes its way into ground and surface waters. The most relevant regulatory mechanisms for realizing these reductions fall under the jurisdiction of the U.S. Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP). FDEP is currently overhauling Florida's water regulatory framework in the shadow of federal oversight. The overhaul includes assuming responsibility for permitting under the National Pollution Discharge Elimination System (NPDES), assessing all of the state's waterways and establishing Total Maximum Daily Loads (TMDLs), or water quality standards, for those designated as impaired, and developing 29 Basin Management Action Plans that implement the TMDLs across all 52 of Florida's watersheds. These regulatory changes under existing law have as great a likelihood of reducing nutrient loads and improving water quality in Florida as would new laws enacted as a direct response to red tides. Supplemental ordinances from local governments may improve local conditions, but Florida's future water quality will largely be determined by rigorous enforcement of permitting requirements, as well as the new standards being developed and the programs being designed to implement them.

Are there any viable control technologies for combating Florida red tides?

There are a variety of ways to control, kill and/or remove *K. brevis* cells from the water column. It is easy to do this in a small, contained environment but controlling red tide blooms at the scales that we normally find them in coastal and marine environments is far more challenging. Research is being conducted on a handful of viable technologies, but the conditions under which these control technologies can be used will be limited in the near term. The most likely applications might be found in intercoastal waterways and canals. Open-water applications pose the most difficult challenges for control technologies, and technological fixes for large-scale blooms remains unlikely over the short to medium term.

How can oversight of Florida's red tide research and management activities be improved?

The governance of both research and management can be improved upon by redesigning, refunding and reconvening the Florida Harmful Algal Bloom Task Force, and creating a mechanism that provides for periodic external reviews of the entire HAB program. The Florida Harmful Algal Bloom Task Force was first established in 1997 as an ad hoc advisory body to address harmful algal bloom (HAB) issues in Florida waters. In 1999 it was legislatively authorized to provide a handful of governance and oversight functions, but it has since become dormant. The need to perform the functions outlined in its original legislative mandate is as strong today as it was when it was established. The composition of the Task Force would benefit from a broader and more balanced representation of societal interests. Florida's HAB research and management programs could also benefit from periodic external reviews. External reviews could help mediate some of the most contentious scientific disputes, endorse program areas that are performing well, outline measures for improvement, and help to restore trust with disaffected stakeholders.

REFERENCES

Abraham, W.M. and D.G. Baden. 2001. Mechanisms of red tide-induced bronchial responses [abstract]. International Society of Exposure Analysis Conference. p. 126.

Abraham, W.M., A.J. Bourdelais, A. Ahmed, S. Serebriakov, and D.G. Baden. 2005. Effects of inhaled brevetoxins in allergic airways: toxin-allergen interactions and pharmacologic intervention. *Environmental Health Perspectives* 112:632–637.

Adams, C. M., D. Mulkey, A. Hodges, and J. W. Milon. 2000. Development of an economic impact assessment methodology for occurrence of red tide. Gainesville, FL: Institute of Food and Agricultural Sciences, Food and Resource Economics Department, University of Florida. Staff Paper SP 00-12.

Adams, C., S. Larkin, D. Mulkey, A. Hodges, and B. Ballyram. 2002. Measuring the Economic Consequences and Public Awareness of Red Tide Events in Florida. St. Petersburg, FL: Harmful Algal Task Force, Florida Fish and Wildlife Conservation Commission. 156 p.

Anderson, D.A. 1997. Turning back the harmful red tide. *Nature* 388:513-514.

Anderson, D.M. 2004. Prevention, control and mitigation of harmful algal blooms: multiple approaches to HAB management. In: Hall, S., S. Etheridge, D. Anderson, J. Kleindinst, M. Zhu, and Y. Zou (eds.). *Harmful Algae Management and Mitigation*. Singapore: Asia Pacific Economic Cooperation. APEC Publication No. 204-MR-04.2. p. 177-181.

Anderson, D.M., P.M. Glibert, and J.M. Burkholder. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition and consequences. *Esturaries* 25(4b):704-726.

Anderson, D.M., P. Hoagland, Y. Kaoru, and A.W. White. 2000. Estimated Annual Economic Impacts of Harmful Algal Blooms (HABs) in the United States. Woods Hole, MA: Woods Hole Oceanographic Institution. Technical Report WHOI 2000-11. 97 p. (http://www.whoi.edu/redtide/pertinentinfo/Economics_report.pdf)

Anderson, D.M, M.R. Sengco, A. Li and S.E. Beaulieu. 2004. Control of Florida Red Tide Using Phosphatic Clay. Bartow, FL: Florida Institute of Phosphate Research. FIPR Report No. 03-138-207.

Apland, J.P., M. Adler and R.E. Sheridan. 1993. Brevetoxin depresses synaptic transmission in guinea pig hippocampal slices. *Brain Research Bulletin* 31:201-207.

Archambault, M-C., J. Grant, and V. M. Bricelj. 2003. Removal efficiency of the dinoflagellate *Heterocapsa triquetra* by phosphatic clay, and implications for the mitigation of harmful algal blooms. *Marine Ecology Progress Series* 253:97-109.

Archambault, M.C., V. M. Bricelj, J. Grant, and D.M. Anderson. 2004 Effects of suspended and sedimented clays on juvenile hard clams, *Mercenaria*, within the context of harmful algal bloom mitigation. *Marine Biology* 144:553-565.

Baden, D.G., A.J. Bourdelais, H. Jacocks, S. Michelliza and J. Naar. 2005. Natural and derivative brevotoxins: historical background, multiplicity and effects. *Environmental Health Perspectives* 113(5):621-625.

Bauer, M. (ed.). 2006. Harmful Algal Research and Response: A Human Dimensions Strategy. Woods Hole, MA: National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution. 58 p.

Belousek, D.W. 2004. Scientific consensus and public policy: the case of *Pfiesteria*. *The Journal of Philosophy, Science & Law* Vol 4. 33 p. (http://www.psljournal.com/archives/papers/pfiesteria.cfm)

Boesch, D.F. 1998. The Cambridge Consensus: Forum on Land-Based Pollution and Toxic Dinoflagellates in Chesapeake Bay, October 16, 1997. Cambridge, MD: Center for Environmental Science, University of Maryland.

Boesch, D.F., D.M. Anderson, R.A. Horner, S.E. Shumway, P.A.Tester, and T.E. Whitledge, 1997. Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation. Silver Spring, MD: NOAA Coastal Ocean Program. Decision Analysis Series No. 10. 46 p.

Boesch, D.F., N.E. Armstrong, C.F. D'Elia, N.G. Maynard, H.W. Paerl, and S.L. Williams. 1993. Deterioration of the Florida Bay Ecosystem: An Evaluation of the Scientific Evidence. Cambridge, MD: Center for Environmental Sciences, University of Maryland. Report to the Interagency Working Group on Florida Bay. 32 p. (http://www.umces.edu/President/fb93rep.pdf)

Bossart, G.D., D.G. Baden, R. Ewing, B. Roberts and S.Wright. 1998. Brevetoxicosis in manatees from the 1996 epizootic: gross, histopathologic and immunocytochemical features. *Toxicologic Pathology* 26 (2):276-282.

Brand, L.E. and A. Compton. 2007. Long term increase in *Karenia brevis* abundance along the Southwest Florida coast. *Harmful Algae* 6:232-252.

Bronk, D.A., M.P. Sanderson, M.R. Mullholland, C.A. Heil, and J.M. O'Neil. 2004. Organic and inorganic nitrogen uptake kinetics in field populations dominated by *Karenia brevis*. In: Steidinger, K.A., J.H. Landsberg, C.R. Tomas, and G.A. Vargo (eds.). *Harmful Algae 2002. Proceedings of the Xth International Conference on Harmful Algae, St. Pete Beach, FL, October 21-25, 2002*. St. Petersburg, FL: Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography and IOC/UNESCO. p. 80-82.

Bronk, D.A., J.H. See, P. Bradley and L. Killberg. 2006. DON as a source of bioavailable nitrogen for phytoplankton. *Biogeosciences Discussions* 3:1247-1277. (http://www.biogeosciences-discuss.net/3/1247/2006/bgd-3-1247-2006.pdf)

Charlotte Harbor National Estuary Program. 2005. Environmental Indicators for the Charlotte Harbor National Estuary Program. Fort Meyers, FL: Charlotte Harbor National Estuary Program. Technical Report 05-1. 69 p. (http://www.chnep.org/info/admin/EnvironmentalIndicators2005.pdf

Choi, H.G., P.Y. Lee, S. J. Yun, W.C. Lee, and H.M. Bae. 1999. Control of *Cochlodinium polykrikoides* blooms and absorption of nutrients in the seawater by clay and yellow loess. *Bulletin of National Fisheries Research and Development Institute (Pusan Korea)* 57:105-110.

Conservancy of Southwest Florida. 2005. Estuaries Report Card for Southwest Florida. 16 p. (http://www.chnep.org/info/EstuariesReportCard200516pg.pdf)

Dixon, K.L. 2003. Red Tide Bloom Dynamics with Respect to Rainfall and Riverine Flow. Sarasota, FL: Mote Marine Laboratory. Technical Report No. 795.

Evans, G. and L. Jones. 2001. Economic Impact of the 2000 Red Tide on Galveston County, Texas: A Case Study. TX: Texas Parks and Wildlife. TPWD No. 666226.

Fleming, L.E., L.C. Backer and D.G. Baden. 2005. Overview of aerosolized Florida red tide toxins: exposures and effects. *Environmental Health Perspectives* 113(5):618-620.

Fleming L.E., B. Kirkpatrick, L.C. Backer, J.A. Bean, A. Wanner. A. Reich A, D. Dalpra, R. Tamer, J. Zaias, Y.S. Cheng, R. Pierce, J. Naar, W.M. Abraham, R. Clark, Y. Zhou, M.S. Henry, D. Johnson, G.V. DeBogart, G.D. Bossart, M. Harrington and D.G. Baden. 2005. Initial evaluation of the effects of aerosolized Florida red tide toxins (brevetoxins) in persons with asthma. *Environmental Health Perspectives* 113(5):650-656.

Fleming L.E., B. Kirkpatrick, L.C. Backer, J.A. Bean, A. Wanner, A. Reich, D. Dalpra, J. Zaias, Y.S. Cheng, R. Pierce, J. Naar , W.M. Abraham, and D.G. Baden. 2007. Aerosolized red-tide toxins (brevetoxins) and asthma. *Chest* 131(1):187-194.

Flewelling, L.J., J.P. Naar, J.P. Abbott, D.G. Baden, N.B. Barros, G.D. Bossart, M. Bottein, D.G. Hammond, E.M. Haubold, C.A. Heil, M.S. Henry, H.M. Jacocks, T.A. Leighfield, R.H. Pierce, T.D. Pitchford, S.A. Rommel, P.S. Scott, K.A. Steidinger, E.W. Truby, F.M Van Dolah, and J.H. Landsberg. 2005. Brevetoxicosis: red tides and marine mammal mortalities. *Nature* 435:755-756.

Florida Department of Agriculture and Consumer Services (FDACS). 2002. Red Tide Regulations. Technical Bulletin No. 2. 4 p.

Florida Department of Environmental Protection (FDEP). 2005. Florida's Total Maximum Daily Load Program: The First 5 Years. A Report to the Legislature and Governor. Tallahasee, FL: Division of Water Resource Management.

Florida Department of Environmental Protection (FDEP). 2006. Integrated Water Quality Assessment for Florida: 2006 305(b) Report and 303(d) List Update. Tallahassee, FL: Division of Water Resource Management, Bureau of Watershed Management. 235 p.

Florida Department of Environmental Protection (FDEP). 2007. Florida Water Policy. (http://www.dep.state.fl.us/water/default.htm). Accessed on March 29, 2007.

Florida Fish and Wildlife Conservation Commission (FWC). 2005. Florida's Wildlife Legacy Initiative. Florida's Comprehensive Wildlife Conservation Strategy. Tallahassee, FL: Florida Fish and Wildlife Conservation Commission. (http://myfwc.com/wildlifelegacy/review/FL_Strategy.pdf).

Florida Fish and Wildlife Research Institute (FWRI). 2007a. Red Tides in Florida. (http://www.floridamarine.org/features/print_article.asp?id=24936). Accessed on March 26, 2007.

Florida Fish and Wildlife Research Institute (FWRI). 2007b. Looking at the Florida Red Tide Historical Database. (http://www.floridamarine.org/features/print_article.asp?id=25871). Accessed on March 26, 2007.

Florida Fish and Wildlife Research Institute (FWRI). 2007c. Frequently Asked Questions about the 2005 Offshore Benthic Mortality Event and Red Tide. (http://www.floridamarine.org/features/print_article.asp?id=25888). Accessed on March 26, 2007.

Florida Fish and Wildlife Research Institute (FWRI). 2007d. An Evaluation of FWRI's Historical Red Tide Database. (http://research.myfwc.com/features/view_article.asp?id=27095). Accessed on March 26, 2007.

Florida Oceans & Coastal Resources Council. 2007. Investing in Florida's Coastal & Oceans Future. Annual Science Research Plan. FY 2007-08. 60p. (http://www.floridaoceanscouncil.org/meetings/files/Research_Plan_FY07-08.pdf)

Florida Senate. 2003. Committee on Natural Resources. Review of Progress in Implementing the Total Maximum Daily Load (Water Quality Improvement) Program by the Department of Environmental Protection. Florida: Committeee on Natural Resources, The Florida Senate. Interim Progress Report 2003-136. 8 p.

Glibert, P.M., J. Harrison, C. Heil, and S. Seitzinger. 2006. Escalating worldwide use of urea – a global change contributing to coastal eutrophication. *Biogeochemistry* 77:441-463.

Habas, E.J. and C. Gilbert. 1975. A preliminary investigation of the economic effects of the HAB of 1973-1974 on the west coast of Florida. In: V.R. LoCicero (ed.) *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms.* Wakefield, MA: The Massachusetts Science and Technology Foundation. p. 499-505.

Haubois, A-G., Bricelj, V.M. and M.A. Quilliam. 2005 Transfer of brevetoxins to the benthos in the context of clay mitigation of *Karenia brevis* blooms [poster]. In: NOAA. *Third Symposium on Harmful Algae in the U.S., Pacific Grove, CA. October 2-7, 2005*. p. 107

Hauserman, J. 2007. Florida's Coastal and Ocean Future: A Blueprint for Economic and Environmental Leadership. New York: National Resources Defense Council. 28 p.

Havens, J. 2004. A Stable Isotopic Examination of Particulate Organic Matter During *Karenia brevis* Blooms on the West Florida Shelf: Hints at Nitrogen Sources in Oligotrophic Waters. Masters Thesis. College of Marine Science, University of South Florida.

Heil, C.A., M. Revilla, P.M. Glibert and S. Murasko. 2007. Nutrient quality drives differential phytoplankton community composition on the southwest Florida shelf. *Limnology and Oceanography* 52(3):1067-1078.

Hoagland, P., D.M. Anderson, Y. Kaoru, and A.W. White. 2002. The economic effects of harmful algal blooms in the United States: estimates, assessment issues, and information needs. *Estuaries* 25(4b):819-837.

Hoagland, P. and S. Scatasta. 2006. The economic effects of harmful algal blooms. In: Graneli, E. and J. Turner (eds.). *Ecology of Harmful Algae*. Dordrecht, The Netherlands: Springer-Verlag. p. 391-401.

Hu, C., F.E. Mueller-Karger, and P.W. Swarzenski. 2006. Hurricanes, submarine groundwater discharge, and Florida's red tides. *Geophysical Research Letters* 33:L11601.

International Council for the Exploration of the Seas (ICES). 2007. ICES Workshop on Time Series Data Relevant to Eutrophication Ecological Quality Objectives [WKEUT], September 11-14, Tisvildeleje, Denmark. ICES CM 2006/ACE:07. 67 p.

Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: The IPCC 4th Assessment Report. (http://www.ipcc.ch/) Accessed on June 1, 2007. In Press.

Johansson, J.O.R. and R.R. Lewis, III. 1992. Recent improvements in water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA. In: Vollenweider, R.A., R. Marchetti and R. Viviani (eds.). *Marine Coastal Eutrophication. The Response of Marine Transitional Systems to Human Impact: Problems and Perspectives for Restoration. Science of the Total Environment, Supplement* p. 1199-1216.

Kemppainen, B.W., W.G. Reifenrath, R.G. Stafford, and M. Mehta. 1991. Methods for in vitro skin absorption studies of a lipophilic toxin produced by red tide. *Toxicon* 66:1-17.

Kirkpatrick, B., L.E. Fleming, D. Squicciarini, L.C. Backer, R. Clark, W. Abraham, J. Benson, Y.S. Cheng, D. Johnson, R. Pierce, J. Zaias, G.D. Bossart, and D.G. Baden. 2004. Literature review of Florida red tide: implications for human health effects. *Harmful Algae* 3:99-115.

Kirkpatrick, B., J. Bean, L.E. Fleming, L.C. Backer, R. Akers, A. Wanner, D. Dalpra, K. Nierenberg, A. Reich, and D. Baden. 2007. Aerosolized red tide toxins (brevetoxins) and asthma: a 10 day follow up after 1 hour acute beach exposure. In: Moestrup, O. et al (eds). Proceedings of the 12th International Conference on Harmful Algae. International Society for Harmful Algae and Intergovernmental Oceanographic Commission of UNESCO. In press.

Kirkpatrick, B., R. Pierce, M. Henry, P. Blum, S. Osborne, K. Nierenberg, L. Fleming, Y. Cheng, A. Reich, D. Baden, and L. Backer. Inland transport of aerosolized Florida red tides. In Preparation.

Lapointe, B.E. and B.J. Bedford. 2006. Drift *Rhodophyte* Blooms Emerge in Lee County, FL: Evidence of Escalating Coastal Eutrophication. Final Report to Lee County and the City of Bonita Springs. 53 p.

Lapointe, B.E., B.J. Bedford, L. Brand, and C.S. Yentsch. 2006. Harmful Algal Blooms in Coastal Waters of Lee County, FL. Bloom Dynamics and Identification of Land-Based Nutrient Sources. Phase II Final Report to Lee County.

Larkin, S.L. and C.M. Adams. Harmful algal blooms and coastal business: economic consequences in Florida. *Society & Natural Resources*. In press.

Lenes, J.M., B.P. Darrow, C. Catrall, C.A. Heil, G.A. Vargo, M. Callahan, R.H. Byrne, J.M. Prospero, D.E. Bates, K.A. Fanning and J.J. Walsh. 2001. Iron fertilization and the *Trichodesmium* response on the West Florida Shelf. *Limnology and Oceanography* 46:1261-1277.

Magana, H.A. and T.A. Villareal. 2006. The effect of environmental factors on the growth rate of *Karenia brevis* (Davis) G. Hansen and Moestrup. *Harmful Algae* 5:192-198.

Magnien, R.E. 2001. The dynamics of science, perception, and policy during the outbreak of *Pfiesteria* in the Chesapeake Bay. *BioScience* 51(10):843-852.

Marvin, K.T. and R.R. Proctor. 1964. Preliminary Results of the Systematic Screening of 4,306 Compounds as Red Tide Toxicants. U.S. Fish and Wildlife Service. Data Report 2. 85 p.

Moore, C. 2006. Fear of Red Tide Remains. *St. Petersburg Times*. July 26, 2006.

Mullholland, M.R., P.W. Bernhardt, C.A. Heil, D.A. Bronk, and J.M. O'Neil. 2006. Nitrogen fixation and release of fixed nitrogen by *Trichodesmium* spp. in the Gulf of Mexico. *Limnology and Oceanography* 51(4):1762-1776.

National Oceanic and Atmospheric Administration (NOAA). 2000. The Florida Bay Science Oversight Panel. (http://www.aoml.noaa.gov/flbay/oversight_panel.html) Accessed on June 28, 2007.

National Oceanic and Atmospheric Administration (NOAA). 2001. Prevention, Control and Mitigation of Harmful Algal Blooms: A Research Plan. Submitted to the United States Congress September 2001 by the National Sea Grant College Program, Office of Oceanic and Atmospheric Research, NOAA. 28 p.

National Oceanic and Atmospheric Administration (NOAA). 2004. Action Plan for Harmful Algal Blooms and the Gulf of Mexico Coastal Ocean Observing System: Results from a Regional Workshop. NOAA Coastal Services Center. NOAA/CSC/20516-PUB. 27 p.

National Oceanic and Atmospheric Administration (NOAA). 2006. NOAA Awards Florida Fish and Wildlife Commission $4.7 Million Over Five Years to Study the Role of Nutrients in State Red Tide Events. NOAA Press Release. October 11, 2006.

O'Shea, T.J., G.B. Rathbun, R.K. Bonde, C.D. Buergelt, and D.K. Odell. 1991. An epizootic of Florida manatees associated with dinoflagellate bloom. *Marine Mammal Science* 7:165-179.

Paytan, A., G.G. Shellenbarger, J.H. Street, M.F. Gonneea, K. Davis, M.B. Young and W.S. Moore. 2006. Submarine groundwater discharge: an important source of new inorganic nitrogen to coral reef ecosystems. *Limnology and Oceanography* 51:343-348.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a Course for Sea Change. A Report to the Nation. Arlington, VA: Pew Oceans Commission. 144 p.

Pierce, R. H. , M.S. Henry, J. Lyons, G.E. Rodrick, P. Aaronson, and T.A. Leighfield, 2003. Comparison of red tide toxin reduction in clams using ozone purification and relay cleansing. In: Villalba, A., B. Reuera, J.L. Romalde and R. Beiras (eds.). *Molluscan Shellfish Safety. Proceedings of the 4th International Conference on Molluscan Shellfish Safety, Santiago de Compostela, Spain, June 4 – 8, 2003.* Xunta de Galicia, Conselleria de Pescae Asuntos Maritimos: IOC/UNESCO. p. 145-150.

Pierce R.H., M.S. Henry, C.J. Hingham, P. Blum, M.R. Sengco, and D.M. Anderson. 2004. Removal of harmful algal cells (*Karenia brevis*) and toxins from seawater culture by clay flocculation. *Harmful Algae* 3(2):141-148.

Ramsdell, J.S., D.M. Anderson, and P.M. Gilbert (eds.). 2005. HARNNESS, Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015. Washington, DC: Ecological Society of America. 96 pp. (http://www.whoi.edu/redtide/nationplan/HARRNESS.pdf)

Rounsefell, G.A. and J.E. Evans. 1958. Large-scale Experimental Tests of Copper Sulfate as a Control for the Florida Red Tides. U.S. Department of the Interior, Fish and Wildlife Service. Special Scientific Report – Fisheries No. 270. 57 p.

Sarasota Bay Estuary Program. 2006. The State of the Bay 2006. Celebrating Our Greatest Natural Asset. Sarasota, FL: Sarasota Bay Estuary Program. 39 p.

Schneider, K.R., R.H. Pierce, and G.E. Rodrick,. 2004. The degradation of *Karenia brevis* toxins utilizing ozonated seawater. *Harmful Algae* 2: 101-107.

Sengco, M. R. and D.M. Anderson. 2004. Controlling harmful algal blooms through clay flocculation. *Journal of Eukaryotic Microbiology* 51(2):169-172.

Sengco, M.R., A-G. Haubois, V.M. Bricelj, J. Grant, J. and D.M. Anderson. 2005. Flow effects on interactions between *Karenia brevis* and clay used in HAB mitigation [abstract]. In: NOAA. *Third Symposium on Harmful Algae in the U.S., Pacific Grove, CA. October 2-7, 2005.* p. 59

Sengco, M.R. Prevention and Control of *Karenia brevis* blooms. In preparation.

Singer, L.J., T. Lee, K.A. Rosen, D.G. Baden and W.M. Abraham. 1998. Inhaled Florida red tide toxins induce bronchoconstriction (BC) and airway hyperresponsiveness (AHR) in sheep. *American Journal of Critical Care Medicine* 157(3):A158.

Smayda, T.J. 1990. Novel and nuisance phytoplankton bloom in the sea: evidence for a global epidemic [abstract]. In: Graneli, E., B. Sundstrom, L. Edler and D.M. Anderson (eds.) *Toxic Marine Phytoplankton: Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton, held June 26-30 in Lund, Sweden*. New York: Elsevier. 554 p.

Smith, G.B. 1975. The 1971 red tide and its impact on certain reef communities in the eastern Gulf of Mexico. *Environmental Letters* 9(2):141-152.

Smith, G.B. 1979. Relationship of eastern Gulf of Mexico reef-fish communities to the species equilibrium theory of insular biogeography. *Journal of Biogeography* 6:49–61.

Spinner, K. 2007. Red Tide May Kill Marine Life Even After it Dissipates. *Sarasota Herald-Tribune.* April 23, 2007.

Steidinger, K.A., M. Burklew, and R.M. Ingle. 1973. The effects of *Gymnodinium breve* toxin on estuarine animals. In: Martin, D.F. and G.M. Padilla (eds.) *Marine Pharmacognosy: Action of Marine Toxins at the Cellular Level.* New York: Academic Press. p. 179-202.

Steidinger, K.A., J.H. Landsberg, C.R. Tomas, and J.W. Burns. 1999. Harmful algal blooms in Florida. St. Petersburg, FL: Florida Marine Research Institute. Unpublished technical report submitted to the Florida Harmful Algal Bloom Task Force.

Steidinger, K. A., G.A. Vargo, P.A. Tester, and C.R. Tomas. 1998. Bloom dynamics and physiology of *Gymnodinium breve* with emphasis on the Gulf of Mexico. In: Anderson, D.M., A.D. Cembella and G.M. Hallegraeff (eds.). *Physiological Ecology of Harmful Algal Blooms. NATO ASI Series G Ecological Sciences* 41:133-154.

Tampa Bay Estuary Program. 2007. State of the Bay. 39 p. (http://www.tbep.org/baystate.html) Accessed on July 20, 2007.

Tester, P.A. and K.A. Steidinger. 1997. Gymnodinium breve red tide blooms: initiation, transport, and consequences of surface circulation. *Limnology & Oceanography* 42(5):1039-1051.

Tester, P.A., R.P. Stumpf, and P.K. Fowler. 1988. Red tide, the first occurrence in North Carolina waters: an overview. In: Marine Technology Society and Institute of Electrical and Electronics Engineers. *Oceans '88 Proceedings, Baltimore, MD, October 31-November 2, 1988.* Washington, DC: Marine Technology Society. p.808-811.

Turner, R.E., N.N. Rabalais, B. Fry, N. Atilla, C.S. Milan, J.M. Lee, C. Normandeau, T.A. Oswald, E.M. Swenson, and D.A. Tomasko. 2006. Paleo-indicators and water quality change in the Charlotte Harbor Estuary (Florida). *Limnology & Oceanography* 51(1):18-533.

U.S. Commission on Ocean Policy. 2004. An Ocean Blueprint for the 21st Century: Final Report of the U.S. Commission on Ocean Policy . Washington, DC: U.S. Commission on Ocean Policy.

Vargo, G.A., C.A. Heil, D.N. Ault, M.B. Neely, S. Murasko, J. Havens, K. M. Lester, L.K. Dixon, R. Merkt, J. Walsh, R. Weisberg and K.A. Steidinger. 2004. Four *Karenia brevis* Blooms: A Comparative Analysis. In K.A. Steidinger, J.H. Landsberg, C.R. Tomas, and G.A. Vargo (eds). *Harmful Algae 2002. Proceedings of the Xth International Conference on Harmful Algae, St. Pete Beach, FL, October 21-25, 2002.* St. Petersburg, FL: Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography and IOC/UNESCO. p.14-16.

Vargo, G.A., C.A. Heil, K.A. Fanning, L.K. Dixon, M.B. Neely, K. Lester, D. Ault, S. Murasko, J. Havens, J. Walsh and S. Bell. 2007. Nutrient availability in support of *Karenia brevis* blooms on the central West Florida Shelf: What keeps *Karenia* blooming? Continental Shelf Research. In press.

Waite, M. and C. Pittman. 2005. Satellite Photographs Show Losses. *St. Petersburg Times*. May 22, 2005.

Walsh, J.J., J.K. Joliff, B.P. Darrow, J.M. Lenes, S.P. Milroy, A. Rensen, D.A. Dieterle, K.L. Carder, F.R. Chen, G.A. Vargo, R.H. Weisberg, K.A. Fanning, F.E. Mueller-Karger, E. Shinn, K.A. Steidinger, C.A. Heil, C.R. Tomas, J.S. Prospero, T.N. Lee, G.J. Kirkpatrick, T.E. Whitledge, D.A. Stockwell, T.A. Villareal, A.E. Jochens, and P.S. Bontempi. 2007. Red tides in the Gulf of Mexico: Where, when and why? *Journal of Geophysical Research* 111(C11) C11003.

Walsh, J.J., R. H. Weisberg, D.A. Dietrele, R. He, B.P. Darrow, J.K. Jolliff, K.M. Lester, G.A. Vargo, G.J. Kirkpatrick, K.A. Fanning, T.T. Sutton, A.E. Jochens, D.C. Biggs, B. Nababan, C. Hu, and F.E. Muller-Karger. 2003. Phytoplankton response to intrusions of slope water on the West Florida Shelf: models and observations. *Journal of Geophysical Research* 108(C6):3190.

Weisberg, R. H. and R. He. 2003. Local and deep-ocean forcing contributions to anomalous water properties on the West Florida Shelf. *Journal of Geophysical Research* 108(C6):3184.

Whittle, P. 2007. Sarasota County Fertilizer Law Could be a Model. *Sarasota Herald-Tribune*. May 7, 2007.

Zollo, C. 2006. Battle Over Fertilizer Runoff at Heart of Rules Debate in Sarasota County. *Sarasota Herald-Tribune*. May 22, 2006.

LIST OF ACRONYMS

ACE – Army Corps of Engineers

BMAP – Basin Management Action Plan

BMP – Best Management Practice

CDC – National Centers for Disease Control and Prevention

ECOHAB – Ecology and Oceanography of Harmful Algal Bloom program

EPA – Environmental Protection Agency

FDACS – Florida Department of Agriculture and Consumer Services

FDEP – Florida Department of Environmental Protection

FDOH – Florida Department of Health

FWC – Florida Fish and Wildlife Commission

FWRI – Florida Fish and Wildlife Research Institute

GCOOS – Gulf of Mexico Coastal Observing System

HAB – Harmful Algal Bloom

HABSOS – Harmful Algal Blooms Observing System

ICES – International Council for the Exploration of the Seas

IOOS – Integrated Ocean Observing System

IPCC – Intergovernmental Panel on Climate Change

MPI – Marine Policy Institute

NIEHS – National Institutes for Environmental Health Sciences

NOAA – National Oceanic and Atmospheric Administration

NPDES – National Pollution Discharge Elimination System

NPS – National Park Service

NSF – National Science Foundation

TMDL – Total Maximum Daily Load

GLOSSARY

Acute - Rapid onset, severe, intense

Acute Toxicity - Adverse effects from short-term exposure

Aerosol - Fine particles or liquid droplets dispersed in the air

Algicidal Bacteria - Bacteria ubiquitous on the West Florida Shelf which can influence the growth and decline of algal blooms through direct or indirect interactions

Anoxic - The absence of oxygen

Anthropogenic - Caused or influenced by humans

Benthic - Relating to the bottom of a sea or lake or to the organisms that live there

Best Management Practices - Effective, practical, structural or nonstructural methods which prevent or reduce the movement of sediment, nutrients, pesticides and other pollutants from the land to surface or ground water, or which otherwise protect water quality from potential adverse effects

Biomass - The total mass of living matter in a given habitat

Bioremediation - The use of biological agents, such as bacteria or plants, to remove or neutralize contaminants, as in polluted soil or water

Biota - The animals, plants, fungi, etc., of a region or period

Bloom - The sudden development of conspicuous masses of organisms, as algae, in a body of water

Brevenal - A natural antagonist produced by *Karenia brevis*, counteracting the effects of brevetoxin

Brevetoxin - A neurotoxin produced by *Karenia brevis*

Chronic - Continuing a long time or recurring frequently

Chronic Toxicity - Adverse effects from repeated exposure over long periods of time

Cyanobacteria - A photosynthetic bacterium, generally blue-green in color and in some species capable of nitrogen fixation

Dead Zone - A zone of oxygen-depleted coastal waters too low to support most life in bottom and near-bottom waters, and which is largely attributed to anthropogenic nutrient pollution. Also referred to as hypoxic zones

Desertification - The rapid depletion of plant life and the loss of topsoil at desert boundaries and in semiarid regions, usually caused by a combination of drought and the overexploitation of grasses and other vegetation by people

Dinoflagellate - Any of numerous one-celled organisms found mostly in the ocean, usually having two flagella of unequal length and often an armor-like covering of cellulose

Ecosystem - A community of organisms together with their physical environment, viewed as a system of interacting and interdependent relationships

Estuary - The wide lower course of a river where it flows into the sea; estuaries experience tidal flows and their water is a changing mixture of fresh and saltwater

Eutrophication - Excessive nutrients in a lake or other body of water, usually caused by runoff of nutrients (animal waste, fertilizers, sewage) from the land, and which causes a dense growth of plant life

Flocculation - The process by which a substance or “flocculant” is added to a suspension in order to remove fine particulates by binding with them and causing them to clump together and sink to the bottom

Flux - A flow, discharge or transfer

Groundwater - The supply of fresh water found beneath the Earth’s surface, usually in aquifers, which supply wells and springs

Groundwater Table - The top zone of soil and rock that is saturated with water and which may be only a foot below the ground surface or it may be hundreds of feet down

Human Dimensions - Refers to the suite of social, cultural and economic aspects of human behavior with respect to ecosystems. and can include both the impacts of human activity on ecosystems and ecosystem impacts on human activity

Hypoxic - Referring to low oxygen

Inorganic - Not involving organisms or the products of their life processes; of mineral origin

Lipid Soluble - Organic compounds that are oily to the touch and are insoluble in water

Load - The total amount of material (pollutants) entering a water body from one or multiple sources

Macroalgal - Large aquatic photosynthetic plants that can been seen without the aid of a microscope

Mitigation - Measures taken to reduce adverse impacts

Neurotoxin - A toxin that damages or destroys nerve tissue

Nitrogen Fixation - Conversion of atmospheric nitrogen gas into forms useful to plants and other organisms by lightning, bacteria, and blue-green algae; it is part of the nitrogen cycle

Non point Source Pollution - Pollution sources that are diffuse and without a single identifiable point of origin, including runoff from agriculture, forestry, and construction sites

Observing System - A collection of one or more sensing elements (human and/or instrument) that reside on fixed or mobile platforms

Oligotrophic - When water bodies which are nutrient poor and contain little aquatic plant or animal life

Organic - Characteristic of, pertaining to, or derived from living organisms; made of carbon and hydrogen as the basic building blocks

Oxidation - A chemical reaction that increases the oxygen content of a compound and/or removes electrons from an atom

Ozone - An unstable, poisonous allotrope of oxygen, O_3, that is formed naturally in the ozone layer from atmospheric oxygen, and is also produced in the lower atmosphere by the photochemical reaction of certain pollutants; it is a highly reactive oxidizing agent used to deodorize air, purify water, and treat industrial wastes

Phosphatic Clay - The very fine mineral byproduct of the phosphate ore beneficiation process

Phytoplankton - A subcategory of planktonic species found in fresh and saltwater and which drift near the surface of the water where there is plenty of sunlight for growth

Plankton - Tiny, often microscopic, organisms that inhabit the water column of oceans, seas and bodies of fresh water

Point Source Pollution - The pollution that comes from a specific, identifiable source, such as a pipe or channel

Precautionary Principle - The precautionary principle asserts that when there are threats of serious or irreversible damage to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Predation - The act or practice of capturing another creature (prey) as a means for securing food

Proximate - Close in terms of time and/or space

Runoff - The discharge of water over land into surface water or groundwater, and which can carry pollutants from the air and land into receiving waters

Stormwater - Rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces, but instead flows onto adjacent land or watercourses or is routed into drain/sewer systems

Terrestrial - Of or pertaining to land

Thermocline - An abrupt and dramatic temperature gradient that marks the transition between warm surface waters and the cooler waters below

Tidal Flow - The water current caused by the tides

Total Maximum Daily Load (TMDL) - a pollution "budget" that stipulates the maximum amount of pollution a water body can assimilate without violating water quality standards

Transoceanic - Extending across or traversing the ocean

Trichodesmium - A form of cyanobacteria found throughout the world's oceans and which can provide nutrients through the process of nitrogen fixation

Trophic Species - The multiple organisms that make up a food chain or web. Higher trophic species refer to those at the top of the food chain

Upwelling - A process in which cold, often nutrient-rich waters from the ocean depths rise to the surface

Wastewater - Spent or used water from an individual home, community, farm or an industry that contains dissolved or suspended substances

Watershed - Land area that delivers runoff water, sediment, and dissolved substances to a major river and its tributaries

MOTE MARINE LABORATORY

1600 Ken Thompson Parkway • Sarasota, FL 34236 • (941)388-4441 • www.mote.org