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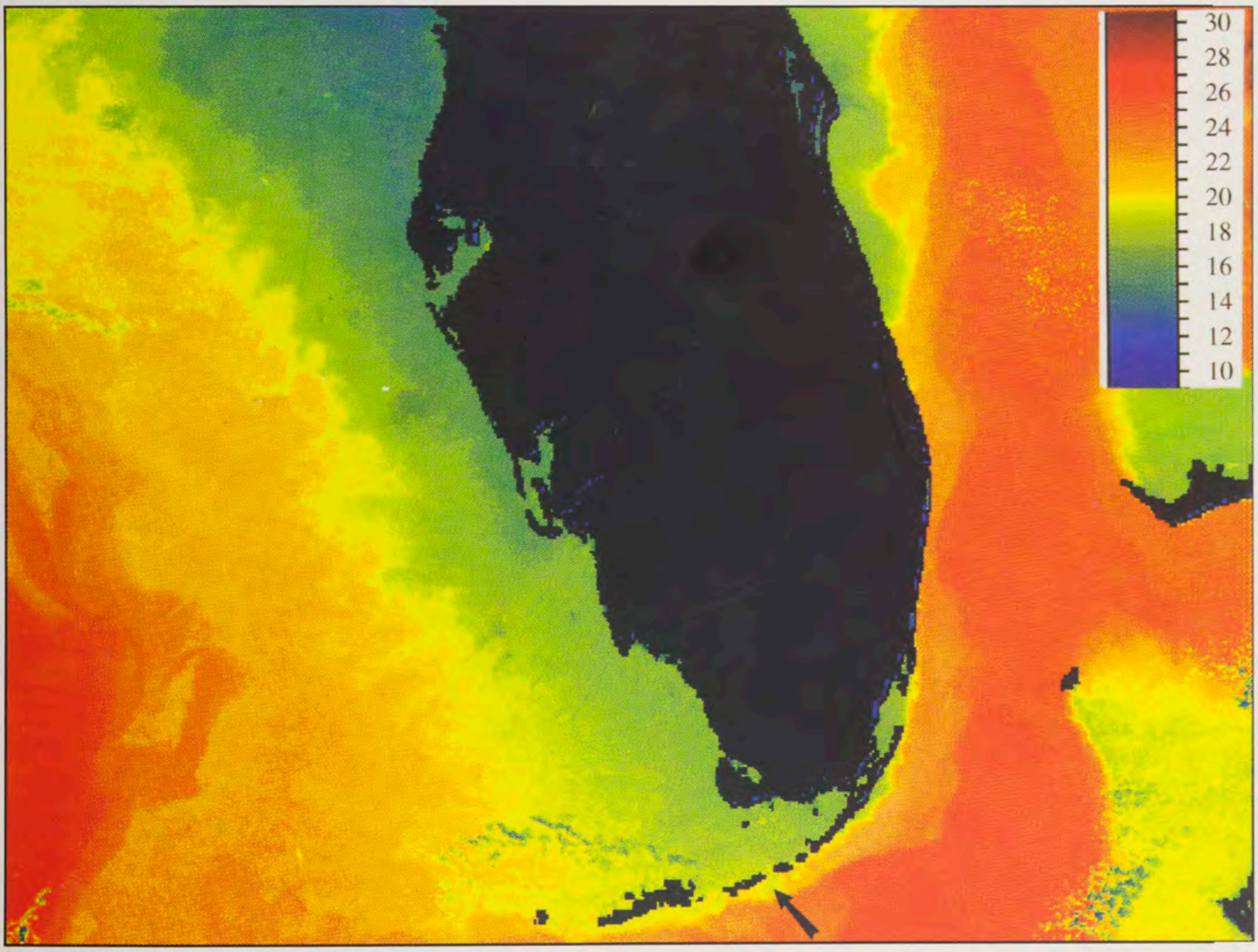

GYMNODINIUM BREVE- A SCIENTIFIC AND JOURNALISTIC ANALYSIS

VOLUME 34
1999

CONTRIBUTIONS IN MARINE SCIENCE

VOLUME 34 1999

PUBLISHED BY

MARINE SCIENCE INSTITUTE
THE UNIVERSITY OF TEXAS AT AUSTIN
PORT ARANSAS, TEXAS 78373-1267

FOUNDED BY E. J. LUND IN 1945

Tracy A. Villareal,
Editor

CONTRIBUTIONS IN MARINE SCIENCE (formerly *Publications of the Institute of Marine Science*) is printed at annual intervals by The University of Texas at Austin Marine Science Institute. The journal will publish reviews and monographs of basic or regional importance in marine science with emphasis on the Gulf of Mexico and surrounding areas.

Both annual personal ($30) and library subscriptions ($80) are welcomed. Inquiries should be sent to T. Villareal, Contributions in Marine Science, Marine Sciences Institute, The University of Texas at Austin, 750 Channel View Dr., Port Aransas, Texas 78373 U.S.A.. (email: cms@utmsi.utexas.edu). Selected back issues prior to 1998 (Vols. 32 and earlier) are available at $10 per volume plus shipping. Potential manuscripts are welcome, but please contact the Editor prior to submission.

The cover image is a 3 February 1995 sea-surface temperature image (NOAA-14) processed by R. N. Stone, NOAA Coastwatch Program, NESDIS. The image shows a warm water intrusion along the soutwest Florida shelf that was associated with a >5,000 km^2 fish kill. *Gymnodinium breve* counts at one station in the Florida Keys exceeded 9.0×10^6 cells L^{-1}.

The image was provided by Dr. P.A. Tester (National Ocean Service, NOAA) from Tester. P.A. and K.A.. Steidinger. 1997. Limnology & Oceanography 42(5)1039-1051.

GYMNODINIUM BREVE IN THE FIELD, IN THE LAB, AND IN THE NEWSPAPER – A SCIENTIFIC AND JOURNALISTIC ANALYSIS OF FLORIDA RED TIDES

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ABSTRACT

This paper consists of a comprehensive historical review and evaluation of Florida red tide research, and an analysis of red tide coverage by the *St. Petersburg Times* from 1953 to 1997. Red tides caused by *Gymnodinium breve* along the Florida Gulf coast are complex; scientists have been asking many of the same questions for nearly 50 years. Red tides also attract considerable media publicity. This paper addresses the following questions: 1. What have scientists learned about Florida red tides since *G. breve* was identified in 1948?, and 2. How well has the issue been covered by the newspaper media? Data compiled for the scientific review/analysis revealed many unanswered questions about the fundamental ecology of *G. breve*. The newspaper analysis revealed many inadequacies in the red tide coverage. More than 500 articles were analyzed, a brief case study performed, appendices compiled, and trends in the coverage delineated. Critiques of content and accuracy noted inadequacies ranging from inconsistency to sensationalism and misinformation. Recommendations for improving coverage were offered in the form of a checklist. The use of improved web-based information sources was suggested as a method to improve communication between scientists, journalists and the public.

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INTRODUCTION

Florida red tides are scientific phenomena often found in the newspaper headlines. Although millions of research dollars have been spent on laboratory and field research, the red tide story still has many missing pages. In recent years, escalating economic and public health impacts associated with algal blooms have tempted some to call them a worldwide epidemic (Hallegraeff 1993, 1995). Others maintain that increased bloom frequencies are an artifact of improved monitoring, population growth, increased development of coastal areas, and an expanding aquaculture industry where the negative effects of blooms are more readily detected.

The lively debate over red tides is not isolated to the scientific laboratory. The impact of red tides on Florida's coastal residences and resorts – and their inevitable media coverage – make red tides a frequent concern for scientists, journalists, and the public. One Florida red tide story widely publicized throughout the world occurred in the spring of 1996 when 149 manatees died from problems related to an unusual red tide along Florida's Gulf coast (Bossart *et al.* 1998). This was only the third time in recorded Florida history when researchers showed that manatees died from red tide-related health problems; the first two episodes in 1963 and 1982 affected about 40 manatees (Landsberg and Steidinger, 1998). The worldwide coverage attracted by the 1996 epizootic event signifies and justifies the heightened public concern over the red tide issue.

This paper analyzes the Florida red tide phenomena from two views: the scientific perspective (Part 1) and the public information perspective (Part 2). The following main questions will be addressed: 1) What do *scientists* know about the harmful algal blooms caused by *Gymnodinium breve* in Florida? Which areas of research warrant the most attention and re-analysis? Which new scientific approaches may help answer some of the same questions scientists have been asking about red tides for years? 2) What does the *public* understand about the phenomena? How good is the communication link (newspaper coverage) between the scientists and the public? Are journalists covering the issue responsibly?

METHODS

A. Part 1 - The Scientific Perspective

A number of historical and scientific databases were used to provide a comprehensive, historical analysis of *G. breve* red tide research, and to highlight those areas warranting further attention. Chronological summary information is followed by a brief evaluation of the progression of research. *The data are presented as they appeared in the original papers. The efficacy of the different methods used in early studies is not compared.* See Appendix 1 for a listing of 10 comprehensive red tide reviews, including the pros and cons of each.

B. Part 2 - The Journalism/Public Information Perspective

Information on the public health and economic impacts of red tides was summarized, and a comprehensive analysis of the newspaper coverage of Florida red tides from 1953 to 1997 using the *St. Petersburg Times* was completed. The analysis includes general assessments of the accuracy, context, and overall journalistic merit. About 500 of 639 red tide-related articles were analyzed (~77%). Recommendations on how to improve communication between scientists, journalists, and the public are offered, and a list of reliable sources of information about red tides for journalists and the general public (World Wide Web sites) are provided in the conclusion. Three appendices were also developed from the articles analyzed. Appendix 2 provides a comprehensive listing of the descriptions used for red tides throughout the coverage tracked. Appendices 3 and 4 provide data on the journalists who covered the red tide story from 1953-1997. Appendix 3 provides a comprehensive list showing the number of journalists at the *St. Petersburg Times* who wrote a story on red tide, the number of articles each wrote, and the total number of red tide-related articles written in each year analyzed. Appendix 4 provides an alphabetical listing of the journalists, along with the date and number of articles written by each one.

PART 1: COMPREHENSIVE ANALYSIS AND REVIEW

A. Historical Perspective

Although the Gulf of Mexico is home to at least 30 toxic phytoplankton species (Steidinger *et al.* 1997), *Gymnodinium breve* is the one that has the greatest impact on the west Florida shelf ecosystem. Blooms of *G. breve* are most notorious for fouling the Florida Gulf coast with fish and invertebrate kills.

G. breve blooms probably occurred along Florida's west coast long before the earliest European explorers recorded them in 1497 (Tester and Steidinger 1997). In the first published reference to fish kills, Alvar Nunez Cabeza de Vaca (1542) explained how the local Indians scheduled their activities according to these events (Steidinger *et al.* 1997). In 1844, about 300 years after this book was published, the first *official* report documented discolored water and massive fish kills along the west Florida (Feinstein 1956; Steidinger and Joyce 1973). Most of this information was anecdotal.

Historically, there were many hypotheses suggested to explain the occasional mass mortalities along Florida's Gulf coast waters. Most were disproven fairly early in the recorded history of red tides, but they are interesting from a historical perspective. According to Taylor (1917) early investigators suggested the following: 1) abnormal Everglades water was reaching the Gulf and killing the flora and fauna, 2) diseases were spreading in the water, or 3) volcanic eruptions were occurring in the area and causing the fish to die. Taylor (1917) proposed the following as more likely explanations: 1) either the mortalities were caused by occluded bottom gases released from the sediments by small seismic disturbances, or 2) they were caused by abnormally large numbers of microalgae.

It took more than 100 years from the initial 1844 reports for the causative microalga to be identified and described. Davis (1948) identified the athecate (unarmored) dinoflagellate, *Gymnodinium breve* in the wake of the notorious 1946-1947 Florida red tide off the coast of Naples documented by Gunter *et al.* (1947). This 11-month red tide was recorded as one of the worst red tides to hit the Florida coast. Furthermore, the phrase "red tide" gained popularity in Florida circa 1948, but various other phrases have been used to describe the same phenomena: red water, bloody water, red plague, yellow water, rotten water, and poisoned water (Hutton 1956).

B. Overview / Natural History

Appendix 1 provides a list of 10 comprehensive analyses, chapter reviews, or annotated bibliographies about Florida red tides that are found in the literature, along with the pros and cons of each.

Florida red tides have occurred in 21 of the last 22 years in the hot spot for red tide activity between Clearwater and Sanibel Island (Joyce and Roberts 1975; Tester and Steidinger 1997). Similar to storms and hurricanes, they have become part of what it means to live in Florida. Red tides have occurred all over the Gulf coast and sporadically along parts of the Atlantic coast as well (Murphy *et al.* 1975; Roberts 1979). About 70% of the red tides recorded since 1878 lasted between 1-4 months; they typically occur in the late summer and fall months. Although early researchers thought blooms originated nearshore and were associated with river runoff and pollution (Rounsefell and Nelson 1966), more recent evidence suggests that blooms initiate 10-40 miles offshore (Steidinger 1975a; Steidinger and Haddad 1981). Given the localized, or patchy, nature of blooms, seed beds have been hypothesized to occur as the source for bloom initiation (Prakash 1967; Steidinger 1975b). After the initiation phase, blooms undergo a growth phase, maintenance phase, and termination phase (Steidinger and Vargo 1988). They are transported inshore by winds, tides, and currents. Among the diverse array of current systems peripherally associated with blooms are the Yucatan Current, Loop Current, and Florida Current. The association of Loop Current intrusions with red tides has attracted attention in recent years (Haddad and Carder 1979; Steidinger and Haddad 1981), but various eddy systems in the Gulf of Mexico are also likely to be instrumental in governing the transport of blooms (Tester and Steidinger 1997). Satellite imagery of these frontal systems holds promise for future studies (Haddad 1982). Table 1 shows the major advances that have been made in red tide research. This general summary is meant to provide context and offer a basic idea of how red tide research has progressed over the years.

Table 1. Summary of Major Advances in *G. breve* Research by Decade

Decade	Major Research Advances	Authors
Late 1940's	Discolored seawater caused by phytoplankton blooms was a familiar phenomena affecting the Florida Gulf coast, albeit one poorly understood	Gunter *et al.* 1947, 1948; Woodcock 1948
1950's-1960's	*G. breve* established as the causative organism of various fish kills; Basic information regarding toxicity of the single-celled alga; Epidemiology of associated human illnesses established	Thomas 1954; Hutton 1956; Starr 1958; Finucane 1964; Ray & Aldrich 1965; Rounsefell & Nelson 1966; Spikes *et al.* 1968
	G. breve culturing techniques	Wilson & Collier 1955
1970's	Basic ecological and physiological principles	Steidinger 1973; Baden & Mende 1978, 1979; Roberts *et al.* 1979
1980's-1990's	More sophisticated biochemical studies; Development of assay detection methods	Pierce *et al.* 1985; Baden *et al.* 1985; Trainer & Baden 1990; Hua *et al.* 1995
	How *G. breve* toxin derivatives act at cell membranes (brevetoxin causes depolarization of the membrane and increases Na+ ion entry into the cell)	Catterall 1985; Huang & Wu 1985; Gawley *et al.* 1992; Rodriguez *et al.* 1994
	Nutrient dynamics	Vargo & Shanley 1985; Vargo & Howard-Shamblott 1990
	Emphasis on the physics behind red tides	Tester *et al.* 1991 Tester & Steidinger 1997

When *G. breve* blooms move inshore after initiation, they can provoke a variety of problems that become cause for public concern including: 1) shellfish contamination in filter-feeding bivalves such as clams, oysters and coquinas (Ray and Aldrich 1965; Hemmert 1975); 2) other human health problems (Taylor 1917; Woodcock 1948; McFarren *et al.* 1965; Steidinger and Joyce 1973; Steidinger 1973; Hemmert 1975; Perez-Cruet 1986) such as watery eyes and coughing from toxic aerosols along the beach, to the more serious symptoms associated with neurotoxic shellfish poisoning (NSP) such as tingling sensations in the extremities, ataxia, hot-cold flashes, slowed pulse, pupil dilation, or mild diarrhea (McFarren *et al.* 1965; Steidinger 1973); 3) considerable economic losses in the tourism industry and costs of beach cleanups (Habas and Gilbert 1974; Jensen 1975); and 4) fish and marine mammal kills (Gunter *et al.* 1948; Steidinger 1973; Smith 1975; Anderson and White 1989; Steidinger 1989; Steidinger *et al.* 1997). Red tides have always been a natural part of the dynamic Gulf coast ecosystem, but the problems associated with them do seem to be on the rise (Anderson 1997; Boesch *et al.* 1997).

Scientists continue to search for answers to questions about the fundamental ecology and biology of *G. breve* red tide blooms. For example, Steidinger recently sketched the *G. breve* life cycle for the first time (Steidinger *et al.* 1997), but the cyst stage has yet to be confirmed within the field or laboratory. Also, not much is known about the factors that affect the intensity of blooms (Tester and Steidinger 1997; Steidinger *et al.* 1997). Nor do scientists fully understand how the physical components of the Gulf coast system interact with the biology of *G. breve* to result in periodic bloom outbursts. *G. breve* reproduces asexually only about 0.2-1 divisions/day (Wilson 1965; Shanley 1985; Shanley and Vargo 1993), but why and how do they outcompete other species in a bloom situation?

Without answers to these questions, the role *G. breve* plays in the Florida ecosystem remains elusive. While scientists search for the answers, Florida citizens continue to become frustrated by the effects of red tides along the beaches, and *G. breve* makes the newspaper headlines seasonally. One of the main obstacles to finding answers to some fundamental questions is the lack of baseline reference data. Although about 30 years of red tide logs are available for analysis (B.S. Roberts *et al.*, Florida Fish and

Wildlife Conservation Commission, St. Petersburg), much of the earlier information was anecdotal and qualitative, making quantitative analyses difficult or impossible.

C. The Organism: *Gymnodinium breve*

1. Basic Anatomy, Morphology and Physiology

It is difficult to correctly identify gymnodinioid species and *G. breve* is no exception. *G. breve* often co-occurs with *G. mikimotoi* during blooms, which complicates the identification process. The use of differential interference microscopy has helped tremendously in this regard (Steidinger *et al.* 1997) and the potential of surface recognition and nucleic acid determination proves holds much promise (P. McGuire, University of Florida, pers. comm.). The following brief discussion tracks the progress made in unraveling the basic anatomy and physiology of *G. breve*.

Davis (1948) first described *G. breve* and outlined its basic cell characteristics after Gunter *et al.* (1947) reported a red tide that occurred along Florida's west coast from November 1946 to January 1947. Davis placed it in the *Gymnodinium* genus because it had a thin periplast without surface markings and it contained chromatophores (yellow-green in color). He described it as a square-type, very flat cell that was 12.7 μ thick. It had roughly equal length and width dimensions that varied from 25.3 μ to 31.6 μ. The girdle was a bit closer to the epicone (top portion of the cell) than the hypocone (lower portion of the cell), and it was not displaced. The sulcus was significantly impressed, and it extended beyond the girdle and into the epicone; at the apex of the epicone it bent to the right around a domelike overhanging process. The epicone was slightly smaller than the hypocone, and many starchlike bodies were found toward the center of the cell.

Dragovich (1967) reported characteristics relating to the basic anatomy and physiology of *G. breve*. He described the five most common *G. breve* morphotypes observed in field samples. Each form presumably corresponded to a particular set of culture conditions or environmental conditions under which the cells were observed. The closing sentence in Dragovich's article was noteworthy: "The fact that forms observed under natural conditions and in culture differed from the original description

(Davis 1948) suggest that further and more detailed research on taxonomy and ecology of *G. breve* is needed." Today, more than three decades later, researchers still need of this type of detailed research; new forms seem to unexpectedly occur which ultimately hinder advances in understanding the broader ecology of *G. breve* blooms at large.

As microscopic techniques in particular and laboratory methods in general have grown more sophisticated over time, so too has the knowledge of *G. breve's* anatomy and physiology advanced since the original descriptions by Davis (1948) and Dragovich (1967). It is now known that the athecate *G. breve* cells typically range from 20-40 µm. The ventral cell side is concave; the dorsal side is convex. *G. breve* cells have a spherical nucleus, and some contain many pigments whereas others barely have any pigmentation (it is considered one of the yellow-green gymnodinioids). Most contain about 10-20 chloroplasts that tend to hug the outer edge of the cell (Steidinger and Joyce 1973). The shape and width of the sulcal intrusion (longitudinal groove) onto the epitheca (upper half) varies with the size and shape of the cell; smaller cells have a wider anterior sulcal intrusion (Steidinger *et al.* 1997). The cingulum that encircles the cell and houses the transverse flagellum is typically displaced such that one end is below the other (Steidinger and Joyce 1973). Its ventral flange is also morphologically distinct from other yellow-green gymnodinioids (Steidinger 1993).

Steidinger (1979) renamed *G. breve* as *Ptychodiscus brevis* because the thecal complex was not characteristic of the *Gymnodinium* species; it had a resistant pellicle and an apical carina. The name was eventually changed back to *G. breve* (Steidinger 1990) but *Ptychodiscus brevis* is still used occasionally in the literature. Nevertheless *G. breve* remains the preferred name until a group of related gymnodinioid dinoflagellates containing fucoxanthin-derivative pigments are placed into a new genus (Steidinger 1990).

G. breve is phototactic and negatively geotactic (Heil 1986; Kamykowski *et al.* 1998), photosynthetic and auxotrophic (Steidinger and Joyce 1973), and can assimilate both organic and inorganic nutrient sources (Vargo and Shanley 1985; Steidinger and Vargo 1988; Steidiger *et al.* 1997). *G. breve*'s endotoxin (brevetoxin) is a nonproteinaceous polyether compound with a low molecular weight (Nakanishi 1985; Lee *et al.* 1989). *G. breve* is one of 2 or 3 gymnodinioid species that produce brevetoxins

(Steidinger *et al.* 1997). Furthermore, in its motile stage, it looks like a leaf that falls through the water, and it swims between 0.70-0.98 m/h (Heil 1986; Steidinger and Joyce 1973; Kamykowski *et al.* 1998). *G. breve* is always present in Gulf waters in low background concentrations of less than 1,000 cells/l (Geesey and Tester 1993), but appropriate hydrodynamic conditions coupled with physiological processes (life cycle and growth/division processes) may be a mechanism that enables it to reach concentrations that exceed background levels. Concentrations that are higher than normal are called bloom conditions.

The reproduction rate of *G. breve* to is 0.2-1 divisions/day (Wilson 1965; Shanley 1985; Shanley and Vargo 1993). This rate does not increase in a bloom situation; the higher cell numbers that characterize a bloom are not the result of rapid cell division. *G. breve* generally divides asexually by oblique binary fission once every 2-5 days (Steidinger *et al.* 1997), but it can also reproduce sexually. Steidinger *et al.* (1997) recently sketched the life cycle for *G. breve*. The sexual cycle starts with a vegetative cell that can undergo mitosis or produce gametes. The gametes fuse into a motile planozygote that has a 2N nucleus and two longitudinal flagella. The planozygote theoretically becomes a resting cell called a hypnozygote, but this has yet to be confirmed. Outlining the life cycle of *G. breve* has presented a formidable research challenge for many years, but it is critical to accurately understand it for ecological research to advance and mitigation/control questions to be addressed responsibly.

2. Geographic Range

Knowing more about the specific distribution of *G. breve* would benefit the research community in many ways. One exciting potential application is the use of *G. breve* as a marker of global warming (Tester *et al.* 1993). Following is a brief sketch of what is known about the organism's geographic distribution to date.

G. breve is usually found in Florida Gulf coast waters (Davis 1948) in background concentrations of less than 1,000 cells/l (Dragovich and Kelly 1966; Steidinger *et al.* 1997). A neritic species (Steidinger *et al.* 1997), it is often found in the central Gulf of Mexico throughout the year at concentrations less than 10 cells/l. Concentrations generally increase closer to the coast, but usually do not exceed 100 cells/l (Geesey and Tester 1993). The organism is found throughout the water column in mixed conditions; during daylight hours or when a well-developed thermocline exists, concentrations are generally higher at the surface.

G. breve is typically found in Florida waters, but it is not restricted to Florida waters. It has been found off Mexico, Texas, Louisiana, Mississippi, Alabama, South Carolina, North Carolina, in the Gulf Stream and around the Chesapeake Bay area (Steidinger 1993; Steidinger *et al.* 1997). Lackey (1956) also found *G. breve* in two samples from a fish kill that occurred along the northern coast of Trinidad in the Caribbean, but the cell counts were never confirmed, and *G. breve* has not been found in the Caribbean since Lackey's report (Tester and Steidinger 1997). Forms resembling *G. breve* have also been found in Spain, Japan, Greece, France, Israel, and New Zealand. In New Zealand, *G. breve*-like forms are being described as new species based on genetics, morphology, and biochemistry (A. Haywood, Cawturon Institute, pers. comm.).

3. Three Environmental Factors Affecting *G. breve*

Temperature, salinity, and light are three critical factors involved in the initiation and maintenance of blooms. The following section chronologically discusses what various laboratory and field experiments have revealed about the general temperature and salinity characteristics of the Gulf of Mexico, including how these diagnostic traits relate to *G. breve*. Table 2 provides a cumulative summary of the information discussed in this section. The data are presented as they appeared in the original papers.

a. Temperature

Temperature has long been considered a significant factor affecting *G. breve* distribution. Information gleaned from United States Coast and Geodetic Survey cruises in the late 1890's and early 1900's provided the basis for establishing the T-S characteristics of the Gulf of Mexico (Galtsoff 1954). An early estimate (Fuglister 1947, cited in Galtsoff 1954) showed that the average winter temperature is 24° C (about 75° F) in the south and 18° C (about 65° F) in the north; this gradient is larger in the eastern Gulf. Average summer temperatures throughout the Gulf hover around a fairly

Table 2. Temperature, Salinity, and Light Effects on *G. breve*

Factor 1 – Temperature	
Temperature effects	
Laboratory studies	**(Temperatures recorded in °C)**
Wilson 1955	Survives 8-10° if temperature is lowered slowly at 1°/hr
Wilson & Collier 1955	Range: 26-28°
Aldrich 1959	Range: 15-30°; no survival ≤ 7° or at 32°
Aldrich 1960	Established importance of parent culture temp.
Hitchcock 1976	Survived 12-33°; greatest growth at 23°; sharp rise in growth between 12-19°; rapid death at 31°
Eng-Wilmot et al. 1977	Optimum: 22°; range: 17-30°; growth declines if < 17°; viability declines if < 31°
Field studies	
Chew 1953	22.93°-24.76°
Finucane and Dragovich 1959	Optimum: 26-28°, but found dense concentrations at 15-18°
Finucane 1964	Optimum: 22°; range: 22-24°
Rounsefell & Nelson 1966	Thrives 16-27°
Rounsefell & Dragovich 1966	Optimum: 20-27°; range: 10-33:
Dragovich & Kelly 1966	13.8-30.6°; higher concentrations at 26-27.9°
Steidinger & Ingle 1972	15-33°
Baldridge 1975	Suggested growth may drop off after 28°

Factor 2 – Salinity	
Salinity effects	
Laboratory studies	
Wilson & Collier 1955	32-34 PSU
Aldrich & Wilson 1960	Optimum: 33 PSU; range: 27-37 PSU; no growth < 24 PSU
Kim & Martin 1974	Optimum: 30-34 PSU
Field studies	
Ketchum & Keen 1948	32.5-33.2 PSU
Gunter et al. 1948	33.1-37.0 PSU
Chew 1953	33.49-34.50 PSU
Odum et al. 1955	33 PSU
Finucane 1964	31.0-34.9 PSU
Rounsefell & Nelson 1966	No real abundance < 30.5 PSU; good growth 31-37 PSU
Dragovich & Kelly 1966	33.68-37.07 PSU; highest concentrations 35.00-36.90 PSU

Factor 3 – Light	
Light effects	
Odum et al. 1955	Variable field conditions
Wilson 1955	Good growth at 175 ft-c for 15 h daily
Aldrich 1959	400-800 ft-c; light levels not limiting
Aldrich 1960	Above 200 ft-c
Aldrich 1962	Not light-limited above 200 ft-c
Eng-Wilmot et al. 1977	About 200 ft-c
Shanley 1985	Photoadaptation; low light adapted sp.
Shanley & Vargo 1993	

consistent 29° C (about 84° F). Annually, the northern Gulf is characterized by a 15-20° C sea surface temperature range, whereas the southern portion sees a smaller range of about 10° C. The central Gulf can be 20° C. Furthermore, February is usually the coolest month of the year for most of the Gulf and August is the warmest (Galtsoff 1954). Cruises by the Fish and Wildlife Service of the United States Department of the Interior (established in 1951) led to reams of temperature data that confirmed these earlier reports.

A plethora of laboratory and field studies have been done to determine the optimal temperature range for the growth and survival of *G. breve*. The reported field temperature range for *G. breve* is 9-33° C, with optimal growth occurring between 22-28° C (cf. Steidinger *et al.* 1997; Rounsefell and Nelson 1966; Steidinger and Ingle 1972; Eng-Wilmot *et al.* 1977).

i. Laboratory studies

• Wilson and Aldrich provided insights on temperature and its role as a factor limiting the distribution of *G. breve*. Wilson (1955) was among the first to perform laboratory-based experiments dealing with the effect of temperature on *G. breve*. He found that *G. breve* survived at 8-10° C if the temperature was lowered by 1° C/h.

• Aldrich (1959) exposed more than 800 cultures to controlled temperature conditions to establish the temperature tolerance of *G. breve*. He reported a growth range of 10-30° C. Population growth generally did not occur at or above 30° C, and survival rates were low. Cell multiplication was visibly slow but still occurred at 15° C. No cells survived at temperatures less than or equal to 7° C, or greater than or equal to 32° C. Aldrich suggested an optimal growth range of 20-27° C, but he emphasized the need for more acclimatization studies to confirm this range. He suggested the idea that *G. breve's* temperature tolerance could theoretically be extended if cultures were acclimatized to varying temperatures. *G. breve* most likely survives slower temperature changes better than fast ones.

• Wilson and Collier (1955) reported breakthrough, successful culturing techniques for *G. breve*. Particularly relevant to this discussion is that Wilson and Collier kept *G. breve* culture temperatures within a tight range of 26-28° C for optimal growth.

• Aldrich (1960) augmented the temperature acclimation concept in a report he published one year earlier (Aldrich 1959). His research team had trouble with their equipment in these studies, but he nevertheless reported preliminary results from a 6-week study on how the temperature of parent cultures influences the growth and survival tolerance of newly inoculated *G. breve* cultures. Cultures inoculated with cells grown at 25° C peaked within three weeks at 25° C and 19° C; they showed reduced populations at 15° C after 6 weeks. Growth stopped after 10 days in 12° C. Furthermore, cultures inoculated with cells grown at 19° C grew slowly at 25° and 19° C, but the population decreased at 15° C. These cultures survived more than 3 weeks at 12° C. Aldrich interpreted these results to mean that there probably is some significance to the temperature of the parent inoculum, but more tests were needed.

• Hitchcock (1976) maintained batch cultures in an enriched seawater medium, and built an aluminum polystat with 30 one-inch holes in the top to monitor temperature. He heated one end of the polystat with a hot plate and cooled the other end with a cold plate to maintain a linear temperature gradient along the bar, and monitored temperature at each position once every minute. *G. breve* survived temperatures between 12-33° C. A sharp rise in growth occurred between 12-19° C, and the greatest growth occurred at 23° C. Growth generally declined between 22-34° C, and rapid death occurred when the temperature reached 31° C, in agreement with Aldrich's (1959) data.

• Eng-Wilmot *et al.* (1977) studied the effects of temperature on two microorganisms, *G. breve* and what they called *Gomphosphaeria aponina*, which was originally thought to be a blue green alga and a potential biocontrol organism for *G. breve*. Recent evidence suggests that it is actually a *Nannochloris* species (Martin and Taft 1998). Similar to Hitchcock (1976), Eng-Wilmot *et al.* constructed a polystat system to ensure temperature control and established a linear temperature gradient between 12-34° C. Optimal growth for *G. breve* occurred between 22- 23° C, which is within the range reported earlier by Aldrich (1959). Growth was generally good between 17-30° C, but declined below 17° C and above 31° C. At 4° C, *G. breve* died within about 5 h, and at 33.5° C the cultures died within 24 h.

ii. Field studies

• Chew (1953) recorded surface temperatures (0-12.9 m depth) from 11 hydrographic stations off Fort Myers, Florida during the November 1952 bloom. Temperatures ranged from 22.93° C (10.9 m depth) at two stations offshore to 24.76° C (0 m depth), which was recorded at one of the stations closer to shore. The area with the heaviest red water was offshore; temperatures were 24.13° C at 0 m depth, 23.61° C at 6 m depth, and 23.55° C at 10 m depth.

• Finucane and Dragovich (1959) reported an optimal field temperature range for *G. breve* between 26-28° C, which was higher than the laboratory optimum reported by Aldrich (1959) and Eng-Wilmot *et al.* (1977). Dense concentrations occurred between 15-18° C. In a later publication, Finucane (1964) recorded the distribution of *G. breve* over a 4-year period (1954-1957) along a 200-mile track of Florida's west coast. He concluded that *G. breve* survives over a relatively wide temperature range; it most often occurred between 10.3-33.2° C. Most blooms, however, occurred within a narrower range – when the water temperature was between 14.0-25.9° C, very close to that reported by Aldrich in 1959 (15-30° C). The greatest number of positive samples and lethal concentrations occurred within an even narrower range – at temperatures between 16.0-17.9° C.

• Rounsefell and Nelson (1966) reviewed the Florida red tide literature information available before 1966. They examined 7 years of field data, and concluded that *G. breve* thrives at temperatures between 16-27° C.

• Dragovich and Kelly (1966) recorded the distribution and monthly occurrence of *G. breve* for a 13-month period from 1964-1965 in the coastal waters of west Florida. The highest concentrations of *G. breve* occurred in September during periods of reduced salinity and temperature. *G. breve* cells were found in water samples within 13.8-30.6° C; cell counts greater than 1,000 cells/l were typically in water between 26.0-27.9° C, and cells were rare or absent at extremely high or low temperatures exceeding these ranges.

• Steidinger and Ingle (1972) reported that *G. breve* was found in Tampa Bay at almost 38° C, which is considerably above the most commonly reported optimal temperatures and above the laboratory temperatures considered to be the upper lethal limit for this species. They reported observations of the 1971 summer red tide in Tampa Bay during which temperatures rose to about 33° C during the day, and speculated that this was probably anomalous for *G. breve*. *G. breve* typically does not grow well (or at all) at temperatures above 32° C.

• Baldridge (1975) presented a working hypothesis that the intensity of *G. breve* blooms was related to the rate of temperature change that occurs in ambient surface waters. His paper was filled with reservations and qualifications that the reader ought to bear in mind. Baldridge studied red tides from 1957-1973 and sea surface temperature data from 1948-1970. He devised the TD, or temperature departure from the average, to quantify variations in the patterns of daily water temperature. He recognized basic temperature patterns common to each of the major red tides in his 17 years of data. For example, a minimum in the TD (compared to the previous year) often corresponded to a major red tide outbreak. Approaching the typical average pattern of temperature change during the winter months, for instance, would indicate an impending bloom. Temperature patterns would essentially suggest if a bloom were likely to occur, but the actual timing and extent of the bloom would be determined by "short-range triggering influences such as nutrient availability, competitor pressure, and/or optimum physical conditions." Baldridge's hypothesis was highly local in its application; it applied only to the data he studied from Egmont Key, Florida. He also made predictions of blooms based on his temperature theory which did not materialize. Although Baldridge's theory received a fair share of skeptical criticism (Anderson and Morel 1976), his work was nevertheless significant in that it represents one of the only reported attempts to use natural factors such as temperature data to predict red tide blooms.

iii. Evaluation

It took about 20 years of synergistic laboratory and field data to establish the temperature tolerances of *G. breve*. Temperature is a critical factor to consider when studying *G. breve* ecology for 2 reasons: 1) temperature has a direct effect on cell physiology (that is, growth rate), and 2) temperature can be used indirectly to indicate physical events such as fronts, which are concentrating mechanisms for *G. breve* that offer potential nutrient supplies. Not much work dealing specifically with temperature has been done since about the 1970's; it is generally accepted that *G. breve* is eurythermal, which is logical given the distribution of *G. breve* throughout the Gulf of Mexico (that is, the northern Gulf of Mexico has different temperature regimes than the southern, more tropical section) and vertically in the water column (that is, *G. breve* has been found down to about 50 m).

Questions about the role of temperature in *G. breve* ecology remain nevertheless. For example, how important is the cellular response to *changes* in temperature? One noteworthy factor that emerged from the literature analysis for this paper was the importance of acclimatization in temperature studies (Aldrich 1959, 1960). Perhaps more analyses such as Baldridge's (1975) hypothesis regarding the role of temperature *changes* in blooms warrant further investigation. Work such as that by Baldridge suggests the importance of short-term upwelling events, for example, in triggering a bloom event. More long-term studies are needed to document temperature changes and the occurrence (frequency, duration, intensity) and overall ecology of blooms. Furthermore, many of the field studies reviewed reported optimal temperature ranges for *G. breve*, but they were often unclear about what optimal meant. How is this measured? Does optimal reflect strictly the number of cells, or the health of the cells? What about nutrient availability – is it valid to interpret temperature data exclusively (that is, without considering the other factors involved in blooms)? Still other early researchers made the distinction between the different temperatures at which normal concentrations and lethal concentrations were found in the field (for example, Finucane 1964; Dragovich and Kelly 1966). However, while the *in situ* temperatures offer an idea of the potential thermal range, they are not necessarily indicative of limits so it is questionable if making these distinctions was significant or valid. Questions such as these warrant further investigation.

b. Salinity

G. breve is relatively stenohaline and prefers salinity values characteristic of coastal and offshore waters (Steidinger *et al.* 1997). Overall, its reportedly optimal salinity range in laboratory and field environments is 31-34 PSU. However, compared to the temperature data just discussed, the salinity data gleaned from the literature does not paint a consistent picture. For example, the most commonly reported range for *G. breve* is 27-37 PSU (Aldrich and Wilson 1960), but Finucane (1964) reported a range of 21-39 PSU, and Rounsefell and Nelson reported values between 31-37 PSU. Following is a chronological discussion of laboratory and field studies done on the relationship between salinity and *G. breve*.

i. Laboratory studies

• As mentioned earlier, Wilson and Collier's study (1955) is best known for its breakthrough methodology regarding the culturing of *G. breve*. This paper also reported some of the earliest information pertaining to the salinity tolerance of *G. breve*. Wilson and Collier used aged seawater from the Gulf of Mexico with an average salinity of 35.5 PSU. The salinity of natural water with high *G. breve* concentrations was between 32-34 PSU.

• Aldrich and Wilson (1960) determined the most commonly quoted salinity range for *G. breve*: 27-37 PSU. They observed reduced growth in waters < 24 PSU, a result that agreed well with the various field studies they also completed. Because *G. breve* did not tolerate fresh or brackish water, Aldrich and Wilson suggested that *G. breve* probably subsists offshore between red tides. Observations by Ray and Aldrich (1967) were in agreement with Aldrich and Wilson's conclusions (1960). Ray and Aldrich reported that *G. breve* and oysters are usually separated by a low salinity barrier; *G. breve* does not survive below 24 PSU, whereas oysters do.

• Kim and Martin (1974) examined relationships between salinity, growth rate, cell size, rate of DNA synthesis and polysaccharide content, toxicity and hemolytic activity. Little was known about the conditions under which *G. breve* produced its toxin, which was hypothesized to be a degradation product of cell wall constituents (Doig and Martin 1972). Kim and Martin saw a potential piece to the toxinogenesis puzzle in salinity-induced changes in growth. They grew *G. breve* cultures with salinity between 22-39 PSU and found 30-34 PSU to be the optimal range, which is within that reported by Aldrich and Wilson (1960). Cells lysed rapidly (within 24 h) below 22 PSU. Minimum cell diameters correlated with optimum salinity, and as the salinity was increased or decreased from the optimum range, the cell DNA and acidic polysaccharide content decreased and the doubling time increased. Kim and Martin also found that the amount of toxin (mg/10^6 cells) obtained and the rate of toxin synthesis varied parabolically with salinity; the lowest amount or rate occurred between 30-34 PSU, doubled at 39 PSU and was slightly greater at 27 PSU (note: the parabola opened upward). The rate of toxin synthesis decreased linearly with DNA and polysaccharide synthesis rates but the significance of this particular finding was left open to interpretation.

Kim and Martin found that the hemolytic activity of *G. breve* toxins did not vary significantly with salinity. Furthermore, they stressed the importance of interpreting their results with caution. They were unsure if their results meant that the ability of *G. breve* to adapt to salinity is initially mediated through a change in cell division with a secondary and parallel change in the rate of DNA. The cultures used were adapted to optimum salinity around 35 PSU; when the salinity regime was rapidly changed, an erratic lag phase resulted. Furthermore, in the earlier tests there were variations in the extracted toxins depending on the salinity of the media used, but when the salinity was changed in later experiments, Kim and Martin did not observe any significant differences.

ii. Field studies

Note: Many of the field studies reported were not specifically focused on the relationship between salinity and *G. breve*, but relevant information was gleaned from them for the purpose of this discussion. (Note: As stated earlier, the results are reported as they appeared in the original literature.)

• Ketchum and Keen (1948) published some of the earliest recorded salinity measurements taken during a red tide bloom. They sampled the west Florida red tide that lasted from November 1946 until January 1947. Salinity values near Sarasota, Florida ranged from 32.9-33. 6 PSU, well within the commonly reported range for *G. breve* (27-37 PSU).

• Gunter *et al.* (1948) performed seawater analyses off Redfish Pass near Captiva Island to the Fort Myers Beach. Blooms have readily occurred throughout this stretch of the Gulf of Mexico. Results indicated a salinity range between 33.1-37.0 PSU, which they estimated to be about average for the southwest Florida coastal waters sampled.

• Chew (1953) provided a 3-dimensional description of the hydrographic regime of a *G. breve* bloom that occurred off of Fort Myers, Florida in November 1952. He mapped distributions and inferred current directions from them; he referred to the warm saline water as Gulf water and the cooler and less saline water as river water. Salinity values ranged from 33.49 PSU (0 m depth) at one nearshore station to 34.97 (12 m depth) at a station farther offshore. The area of the bloom with heavy red water was offshore. It would later be shown that red tides initiate offshore (Steidinger 1975a).

• Slobodkin (1953) hypothesized that a discrete water mass with salinity values lower than the typical surface water in the Gulf of Mexico was necessary to initiate a red tide bloom. He suggested that water masses that would support a *G. breve* bloom were uncommon, and also hypothesized that red tides are coastal phenomena associated with heavy land drainage. This hypothesis was disproven by Steidinger (1975a) and Steidinger and Haddad (1981), who confirmed that *G. breve* blooms initiate offshore, and that *G. breve* is found year-round in the Gulf of Mexico. The water masses capable of supporting it *are* common.

• Odum *et al.* (1955) accumulated data from marine and estuarine waters during and between Florida red tide outbreaks from 1952 to 1954. The hot spot for red tide activity stretched from Clearwater to Naples, and blooms occurred from the coast to about 50 miles offshore. Average salinity was 33 PSU. Odum *et al.* hypothesized that higher salinity is a prerequisite for blooms to occur within estuaries like the Tampa Bay and Charlotte Harbor. For example, when freshwater inputs to Tampa Bay waters are reduced, salinity could range between 32-34 PSU, which could theoretically support a red tide bloom.

• Finucane (1964) recorded the distribution of *G. breve* over a 4-year period (1954-1957) along a 200-mile track of Florida's west coast. He concluded that *G. breve* survives over a relatively wide temperature range, and hypothesized that salinity may act as a barrier limiting its distribution. *G. breve* was never observed in waters with high salinity values (>39.0 PSU) or in estuaries with salinity values less than 21.0 PSU. Lethal cell concentrations (250,000 cells/l) were documented when the salinity varied between

21.0-36.9 PSU, but most of them were recorded in water with salinity values between 31.0-34.9 PSU. Finucane was cautious about setting a lower salinity limit because he had very few samples from low-salinity waters.

• Rounsefell and Nelson (1966) performed a computer analysis of 1954-1961 field data. *G. breve* was generally not found in waters with salinity less than 30.5 PSU. Field observations indicated good growth between 31-37 PSU.

• Dragovich and Kelly (1966) recorded the monthly distribution of *G. breve* from 1964-1965 in the coastal waters of west Florida and found *G. breve* most often in water with salinity values between 33.68-37.07 PSU. In general, the highest concentrations of *G. breve* were reported in September during periods of reduced salinity and temperature. However, the highest cell concentrations fell within a salinity range of 35.00-36.90 PSU, which seems slightly contradictory because water with salinity values between about 35-37 PSU are average or higher-than-average – these are not reduced salinity values, which may suggest methodological problems in the study.

iii. Evaluation

Similar to the temperature data, it took about 20 years of laboratory and field data to establish and confirm salinity tolerances for *G. breve*. The majority of the work was completed in the 1970's. It is generally accepted that *G. breve* is relatively stenohaline and the reported optimal salinity range in both the laboratory and in the field is 31-34 PSU.

That is not to say, however, that the salinity work is complete. For example, Kim and Martin (1974) raised potentially significant issues such as the finding that toxin production increased with increasing salinity. No follow-up work has been published since their study. *G. breve* is typically found in higher-salinity water (27-37 PSU), but most lethal concentrations have been found in water with values between 31-34 PSU. Does this indicate greater toxin production, or simply higher cell numbers? Is increased toxin production solely a function of salinity changes? To what extent does *G. breve* osmoregulate? What other factors could be involved? On one hand, a toxin increase at lower salinity values could indicate osmoregulatory problems. Alternatively, increased concentrations of cells could indicate increased nutrient availability that occurs when the lower salinity estuarine waters mix with the coastal waters; in this case, the increased toxicity would be due to an increase in biomass. In general, it seems extremely important that the physical dynamics of concentrating mechanisms (winds, convergence zones, convection cells) be well-recognized in *G. breve* blooms. Most Florida estuaries do not support blooms if salinity values are below about 24 PSU, but *G. breve* can nevertheless be found in extremely low salinity water (Dortch *et al.* 1998). *G. breve* exhibits elastic behavior in this respect; for example, blooms have occurred in low-salinity Tampa Bay waters (Kim and Martin 1974) and high-salinity, drought-afflicted Bay waters (1970-71; salinity reached 28-30 PSU).

c. Light

i. Laboratory and field studies

Light is an integral factor in the life of a *G. breve* cell. Blooms typically occur in well-mixed conditions, and given its ability to vertically migrate, *G. breve* is exposed to a wide range of light intensities. *G. breve* is a photosynthesizer; without light, it dies (Aldrich 1960, 1962). At the same time, however, *G. breve* is a dinoflagellate, so it generally does well at low light levels (Richardson *et al.* 1983). How low? Following is chronological discussion of the studies that have been done regarding light and *G. breve* that will help answer this question.

• Odum *et al.* (1955) made a few light intensity measurements during the 1952-53 Florida west coast red tide. Intense light conditions (full sunlight with little attenuation) often prevailed in the shallow, red tide zones between 10 - 40 ft (3-13 m) deep. Odum's group took submarine photometer readings at 3-foot intervals, and computed light-extinction coefficients below 3 ft. Sometimes the measurements were low compared to typical coastal waters, thus indicating relatively intense light conditions. For one of the measurements, 40-50% of visible light reached 9 ft (3 m) in a near-bloom patch and in inter-bloom water (Note: 40-50% of visible light would be about 800-1000 $\mu mol/m^2/s$). At other times, however, conditions were much more turbid than typical coastal waters and extinction coefficients were higher.

• Wilson (1955) performed some of the earliest culture experiments with *G. breve*. Good growth occurred with a light intensity of 175 foot-candles for 15 h/day; 8 h at this intensity was not enough light to sustain the *G. breve* population, nor was 150 foot-candles for 15 h/day. Overall, Wilson's results suggested that *G. breve* could grow normally at relatively low light levels.

• Aldrich (1959) confirmed that vegetative *G. breve* cultures survive less than one week without light. Because *G. breve* draws its energy via photosynthesis, this result was not surprising. Aldrich suggested that light levels are not limiting to the growth of *G. breve* in established cultures, which he illuminated continuously with 400-800-foot candles of fluorescent light. He used 5-l unialgal cultures to study the effect of artificial day-night illumination on the pigment and population levels of *G. breve*, and 480-foot candles of fluorescent light for the intermittent illumination. Results indicated that *G. breve* can store enough energy to survive intermittent 12- to 16-hour periods of darkness without reducing its pigments or reproductive rate.

• One year later, Aldrich (1960) reported work in progress. The extent of *G. breve*'s dependence on light as a direct energy source was unknown. No compound or mixture supported *G. breve* without light, even when Aldrich imposed a gradual transition from light to darkness. Growth did not occur any faster with higher light intensity (1000 foot-candles, versus the 500-600 foot-candles he usually used), which confirmed that light intensity above 500 foot-candles is not growth-limiting. No growth occurred at a light intensity of 200 foot-candles. Aldrich did not specify the length of time he exposed the cultures to these intensities. Furthermore, exposing cultures to fluorescent, incandescent, indirect daylight, ultraviolet, and infrared radiation did not recognizably improve growth. However, after 10 days there were no living cells in 60% of the replicate tubes in the ultraviolet-treated cultures and those cultures exposed to filtered light with different wavelengths and similar intensities had the highest cell concentrations in blue or green light.

• Aldrich's 1962 study was probably his most well known regarding the effect of light on *G. breve*. In it he explained that *G. breve* is photoautotrophic which means it requires light and CO_2 or HCO_3- to grow. Aldrich wanted to define *G. breve's* heterotrophic capacities, if any, and wanted to determine if the organic content of Florida river waters and coastal fishes provided an additional energy source for *G. breve*. He grew cultures at 25° C and tested soil and fish extracts from various rivers along

Florida's west coast. None of the organic substances he tested supported the growth of *G. breve* in the dark.

• Eng-Wilmot *et al.* (1977) performed a comparative laboratory study with *G. breve* and *Gomphosphaeria aponina*, originally thought to be a blue-green alga and potential bio-control agent for *G. breve* blooms (note: It was actually a *Nannochloris* species; cf. Martin and Taft 1998). They were primarily looking at the effect of temperature on these organisms, but information about light and *G. breve* can be extracted from their study. No apparent relationship was found between light and the growth of *G. breve* within their constructed polystat, which enabled them to look at various gradients of light along a continuum. Illumination levels were kept relatively constant, and the light intensity at the top of the culture holes in the polystat was 50 +/- 13 foot-candles and 207 +/- 6 foot-candles at the bottom. The overall light intensity incident to the cultures in the polystat was low, consistently about 200 foot-candles. [As noted earlier, Aldrich (1960) found *G. breve* did not grow below 200 foot-candles.]

• Shanley (1985) did her master's thesis on *G. breve* and photoadaptation, which served as the basis for a later paper by Shanley and Vargo (1993). In photoadaptation, phytoplankton cells adjust their photosynthetic units in response to light changes. Among the physiological changes that occur is an increase in cellular carotenoids and chlorophyll at lower irradiances, and vice versa. Changes in growth rates also occur. Shanley's basic conclusion was that *G. breve* can grow over a wide gradient of light intensities, which holds important implications for the ecology of how red tide blooms work under a variety of light conditions. *G. breve* is metabolically flexible as light conditions change and only took about a generation time to photoadapt in Shanley's study. Lower growth rates generally occurred at lower irradiances and higher growth rates at higher irradiances; growth rates varied from 0.16 doublings/day at 24 $\mu E/m^2/sec$ to about 0.43 doublings/day at 90 $\mu E/m^2/sec$. In the paper by Shanley and Vargo (1993), growth was a hyperbolic function of irradiance over a range of 24 to 160 $\mu E/m^2/sec$, which represents about 1.5-10% of full sunlight (less than about 20 m depth in west Florida shelf water column). Growth was saturated at 45 μE, and the compensation light intensity was 6 μE, which indicated *G. breve* to be a low light adapted species. A basic conclusion that emerges is that *G. breve* has the ability to maintain photosynthetic efficiency at high light levels even though it is adapted to low light levels.

ii. Evaluation

Fewer studies have been published on the relationship between light and *G. breve* compared to the literature addressing temperature and salinity. Once it was established that *G. breve* is a photoautotroph, it was generally accepted that it required a limited amount of light. Specific light intensity requirements were quickly determined from various laboratory studies in the mid-1950's to the early 1960's. However, questions remain regarding the application of laboratory-based values to real-world conditions. In the laboratory, variables must be isolated to test their individual effect, but in the real world it is likely to be a *combination* of variables that sustains or enhances the growth of *G. breve*. *G. breve* has been found in offshore and nearshore Gulf of Mexico waters, and at the surface down to about 50 m in the water column; this represents a wide spectrum of light intensities with which it must contend. As shown by Shanley (1985) and Shanley and Vargo (1993), it has the ability to photoadapt but more studies are needed. Considering the significance of light regarding growth rates, it seems surprising that more of these studies have not been done. It is also interesting that the highest concentrations of *G. breve* are typically found at the surface, but physiologically *G. breve* does better at low light levels. Perhaps its carotenoids counter the negative effects of high light (Millie *et al.* 1997). The picture emerging of *G. breve* is that it is an organism capable of adapting to a variety of temperature and light conditions (and to a lesser degree, salinity changes).

4. Nutrients, Trace Metals and More

Along with temperature, salinity and light, understanding the nutrients requirements of *G. breve* plays a significant part in understanding the overall dynamics of how blooms are initiated and maintained. The nutritional factors affecting the growth of *G. breve* have been the subject of many studies since the organism was first identified. Ecological studies on red tide require understanding the nutritional factors that may limit or stimulate growth of algal populations (Wilson 1959). *G. breve* efficiently uses inorganic and organic forms of the macronutrients, P and N, under laboratory and field conditions. It also has chelated trace metal and vitamin requirements (Steidinger *et al.* 1997). The most comprehensive information available about *G. breve* metabolism deals with its macronutrient requirements; far less is known about the micronutrients. Following is a comprehensive discussion of the various studies that have been done to establish the growth requirements of *G. breve*. It is broken down into 5 sections: 1) phosphorus (2.3.4.1), 2) nitrogen (2.3.4.2), 3) metals and vitamins (2.3.4.3), 4) surfactants (2.3.5) and 5) other (2.3.5.1). Table 3 summarizes and categorizes all of the information discussed.

a. Phosphorus

It is well established that blooms occur in low-nutrient conditions. The oligotrophic Gulf of Mexico rarely registers N and P values greater than 0.5 µg-at/l (Steidinger *et al.* 1997). Nevertheless it took a hefty body of often contradictory data to show that N and P do not limit the growth of *G. breve* in the Gulf of Mexico. Also, while N is considered limiting in the marine environment, more information has been published on the role of P in *G. breve* blooms. The following chronologically tracks the phosphorus story.

• The work by Smith (1948) prefaces the phosphorus story. Smith hypothesized that inorganic P limited the growth of all phytoplankton along the west Florida coast. He suggested that increasing its availability would therefore stimulate bloom formation.

• After analyzing water samples from the 1946-1947 bloom, Ketchum and Keen (1948) found that the water supporting the bloom had a much higher total P content than the surrounding water masses. Total P values ranged from 4.9-20.4 µg-at/l, which is 2.5-10 times the normal P concentrations for Gulf waters. Gulf waters typically average no more than about 2.0 µg-at/l TP (Sverdrup *et al.* 1942, cited in Bein 1957). Ketchum and Keen suggested that the excess P either had a terrigenous source such as fertilization, or it was a signature of the surface bloom. Their work had a longevity of about 10 years. Bein (1957; discussed later) found that the water supporting the bloom did *not* have

Table 3. Summary of Nutrients, Trace Metals and More on *G. breve* (continued on following pages)

FACTOR	EFFECT / NOTES	REFERENCE(S)
Phosphorus	Higher-than-average concentrations sustained growth (total P)	Ketchum & Keen 1948
	Bloom did not coincide with maximum total P	Chew 1953
	Observed slight increase in bloom areas	Odum et al. 1955
	Total P content lower in bloom periods	Bein 1957
	Required 0.4 μg-at/l inorganic P	Wilson 1959
	Not limiting	Aldrich 1962; Rounsefell & Nelson 1966
	Better growth with 38 μg P/l in media	Wilson 1965
	Needed at least 6 μg P/l in media to survive	Wilson 1966
	Uses both inorganic and organic P	Vargo & Shanley 1985
	Storage pools and fast uptake rates; not limiting	Vargo & Howard-Shamblott 1990
Nitrogen	Not limiting	Wilson 1959; Aldrich 1962; Rounsefell & Nelson 1966
	Nitrate/nitrite not required	Wilson 1965; Rounsefell & Dragovich 1966
	Ammonium likely source	Wilson 1965; Doig & Martin 1974
	Organic N needed	Wilson 1965
	High affinity for inorganic N, but also stimulated by organic N	Shimizu & Wrensford 1993
Inorganic N, P alone	No effect	Wilson 1965; Doig & Martin 1974
Inorganic N, P combined	Stimulatory	Doig & Martin 1974
Sulfides	Maintain growth in aged seawater medium	Wilson & Collier 1955
Vitamins	Stimulatory	Wilson & Collier 1955; Wilson 1959; Aldrich 1962
Iron	Stimulatory	Kim & Martin 1975
	Supported initial growth but not extended	Wilson & Collier 1955
	Did not improved growth	Wilson 1959
	Stimulatory with chelator	Wilson 1965
	Iron index; stimulatory with humic acids	Ingle & Martin 1971
Zinc	Supported initial growth but not extended	Wilson & Collier 1955
	Needed in trace element mixture; unclear	Wilson 1959

Table 3 (cont.)

FACTOR	EFFECT / NOTES	REFERENCE(S)
Copper	Supported initial growth but not extended	Wilson & Collier 1955
	Lethal; fast-acting	Starr 1958; Marvin 1960; Martin & Olander 1971
	Occasionally supported growth	Wilson 1959
Titanium	Supported initial growth but not extended	Wilson & Collier 1955
	Needed in trace element mixture	Wilson 1959
	Not stimulatory	Martin & Olander 1971
Zirconium	Supported initial growth but not extended	Wilson & Collier 1955
	Lethal; not fast-acting	Starr 1958
	Needed in trace element mixture	Wilson 1959
	Not stimulatory	Martin & Olander 1971
Co, Cr, Al, Si	Supported initial growth but not extended	Wilson & Collier 1955
Rubidium	Supported initial growth but not extended	Wilson & Collier 1955
	Occasionally supported growth	Wilson 1959
Molybdenum	Supported initial growth but not extended	Wilson & Collier 1955
	Occasionally supported growth	Wilson 1959
Barium	Occasionally supported growth	Wilson 1959
Manganese	Supported initial growth but not extended	Wilson & Collier 1955
	Needed in trace element mixture	Wilson 1959
Boron	Needed in trace element mixture	Wilson 1959
Strontium	Supported initial growth but not extended	Wilson & Collier 1955
	Lethal; not fast-acting	Starr 1958
Mercury, Silver	Lethal	Starr 1958
Nickel	Occasionally supported growth	Wilson 1959
Soil extract	Replaced effect of trace metals	Wilson & Collier 1955; Wilson 1959
Chelator	Stimulated growth	Wilson & Collier 1955; Aldrich 1962; Wilson 1965
Buffer (Tris)	Improved growth	Wilson 1965
Gibberelic acid	Increased final cell number	Paster & Abbott 1970

Table 3 (cont.)

FACTOR	EFFECT / NOTES	REFERENCE(S)
Detergent (surfactant)	Lethal	Doig & Martin 1974; Hitchcock 1976; Kim & Martin 1974

unusually high P as a prerequisite for the bloom to occur. The excess P must have been tied up in the biomass simply as a result of high cell concentrations; it is not considered a limiting nutrient for *G. breve*.

• Chew (1953) sampled 11 hydrographic stations off Fort Myers, Florida to provide a 3-dimensional description of the November 1952 *G. breve* bloom. The average surface total P, about 1.11 µg-at/l, decreased with depth. Areas showing a high amount of P (maximum TP was 3.8 µg-at/l, which was just 1/5 of the value reported by Ketchum and Keen in 1948) corresponded to open Gulf waters, whereas areas with low total P values were influenced by river drainage. Of particular relevance to this discussion is Chew's following conclusion: Although higher P values were found in areas where the *G. breve* bloom occurred, the bloom did *not* coincide with areas of maximum total P. Chew did not dismiss another suggested hypothesis that P leaching from the Gulf bottom could stimulate red tide blooms, but he also raised the possibility that blooms could occur after organic matter is released into the water from another bloom such as *Trichodesmium*. The cycle of organic decomposition and inorganic recycling could stimulate a *G. breve* bloom.

• Odum *et al.* (1955) studied the same 1952-1953 Florida red tide. They occasionally found red tide patches with higher-than-normal nutrient concentrations (but they did not specify whether they measured total or dissolved nutrients). The data appeared to support Ketchum and Keen's work (1948). However, they also noted that more typical blooms only showed a *slight* increase in N and P concentrations. *G. breve* was most often found in a relatively nutrient-poor or moderately fertile water regime with a high N:P. Odum *et al.* did not dismiss P as a potentially important controlling factor in red tide blooms, and suggested that it may only take small nutrient injections from rivers and estuaries along Florida's west coast to stimulate *G. breve* blooms. They also hypothesized that increased pollution along coastal areas provided nutrient pulses that stimulated more red tide blooms, a hypothesis that would eventually be contradicted (nutrients in pollution may cause blooms to last longer, but they do not initiate more blooms to occur).

• In a 24-hour study by Hela (1955), the highest concentrations of *G. breve* did not coincide with maximum total P.

• If the work by Ketchum and Keen (1948), Chew (1953), Odum *et al.* (1955) and Hela (1955) deemed the role of P in red tide blooms an unfinished and somewhat confusing story, Bein (1957) began to write its conclusion. He published a literature review on the role of total P in *G. breve* red tide blooms and used various data to sketch the P regime before, during, and after an outbreak. He ignored the inorganic P data because it did not necessarily indicate the productive potential of the water. Contrary to the work of Ketchum and Keen (1948), Bein found that bloom waters were not high in P. Rather, the waters around Florida's west coast had enough P to support *G. breve* blooms throughout the year, a finding that undermined the predictive value of P. Bein emphasized that the P content of water samples from blooms was often *lower* than non-bloom periods. About 0.4 µg-at/l of total P characterized most *G. breve* blooms below 1,000,000 cells/l, and Bein suggested that the waters studied by previous researchers to investigate the relationship between P and blooms were P-enriched beyond average Gulf values for other reasons, which led to errant conclusions.

• Wilson (1959) reported many significant landmark findings about the metabolic requirements of *G. breve*. He closely examined the effects of Ca, P, vitamins, and trace elements on *G. breve*. In the Ca-P experiments, good growth occurred if the Ca concentration mimicked that of the open ocean (about 400 mg/l) and the inorganic P content was at least 0.4 µg-at/l. Optimum growth occurred when the Ca was between 140-400 mg/l and the inorganic P was between 0.4-40 µg-at/l.

• Wilson (1965) wrote a comprehensive paper entitled "The suitability of sea-water for the survival and growth of *Gymnodinium breve* Davis; and some effects of phosphorus and nitrogen on its growth." He added a variety of substances to culture media to see which best stimulated or supported growth. A trace element mixture with EDTA and Fe, combined with an inorganic nutrient mixture (N and P) improved the growth and survival in more than 50% of the samples. Inorganic nutrient mixtures alone did not have a significantly beneficial effect. The common organic buffer known as Tris (hydroxymethyl) aminomethane, which acts as a weak metals-complexing agent, improved growth in most samples. Transferred cultures grew in media with 9.0 µg P/l (.29µM), but not in 6.0 µg P/l, which was in agreement with field data. Also, media with 38 µg P/l (1.23 µM) or more supported higher population levels than media with less than that amount. Similar to his earlier work (1959) then, Wilson's results slightly contradicted Bein's (1957) statements regarding the role of P in *G. breve* blooms; Wilson suggested that P was a more important factor to consider in bloom formation. Furthermore, cultures grew fine when glycerophosphate, an organic form of phosphate, was the only available P source. Wilson also suggested that it is better to measure total P rather than just dissolved P, which would be rapidly consumed by the bloom cells; blooms are dependent upon the environmental water mass conditions that precede it.

• Rounsefell and Nelson (1966) summarized red tide research published up to 1964. Their literature review showed that *G. breve*, like most dinoflagellates, does not require a high concentration of nutrients to grow and bloom into a red tide. In fact, "It seems to be fairly well established that red-tide organisms can and do bloom when nutrient levels are low." As found earlier by Bein (1957), *G. breve* does not require that much (compared to what was originally thought).

• Studies by Vargo and others carried the phosphorus investigation a few steps further. Vargo and Shanley (1985) studied a 3-month bloom along the west Florida coast in 1982. They determined that *G. breve* produces alkaline phosphatase, an enzyme that breaks down organic forms of P, and can therefore satisfy its P requirements using organic phosphorus. Alkaline phosphatase activity (APA) was greatest when ammonia was present. Detecting APA was significant because it means in bloom situations, high numbers of cells can be maintained through regeneration processes; *G. breve* does not rely solely on inorganic P supplies (which are characteristically low). In coastal areas other than high inorganic P areas such as Tampa Bay and Charlotte Harbor, for example, *G. breve* could use organic P. Detecting APA also suggests possible P deficiency in the field community. However, although the populations were P deficient, P did not limit growth; adding N alone increased biomass. Sufficient P (inorganic or organic) was available for growth. In short, the population was N and possibly P limited.

• Vargo and Howard-Shamblott (1990) used semi-continuous cultures to: 1) determine cellular concentrations, and 2) establish relationships between P and growth. *G. breve* can store P into 2 potential storage pools in the presence of excess P. Phosphorus uptake rates were faster than those reported for most dinoflagellate species; turnover rates were relatively quick and the saturation constant (K_s) was low. These results indicated that in offshore, oligotrophic waters with low P conditions, *G. breve* can maintain high populations even with its relatively long generation times. In nearshore waters (about 0.2 μM P) that are influenced by injections from estuaries, P limitation does not occur.

b. Nitrogen

Nitrogen is the primary limiting nutrient in marine waters. However, it has consistently been demonstrated that nitrogen does not normally limit the growth of *G. breve.* Following is a brief sketch of the research that has led up to this basic conclusion.

• Wilson (1959) reported a series of experiments dealing with nitrogen. He found that *G. breve* grew when all inorganic N sources were removed. Wilson interpreted this to mean that *G. breve* was getting the N from the buffer (Tris), the EDTA, or the atmosphere. Wilson's work with N was questionable because he typically used NH-15, Tris, and/or EDTA, which contain ammonia; high ammonia (>1.5μM) can inhibit nitrate reductase activity, which is needed to convert nitrate to nitrite and amines within the cell.

• In two later studies, Wilson (1965, 1967, cited in Martin *et al.* 1971) reported that cultures did not grow unless some form of organic N was in the media; nitrate-nitrite was not required. Ammonium (or secondarily, organic N) was the most likely N source for *G. breve.* One year later, the comprehensive red tide report by Rounsefell and Nelson (1966) was published. The information pertaining to N was generally no different than Wilson's results (1959, 1965) just discussed. Furthermore, Rounsefell and Dragovich (1966) found no significant correlation between the occurrence of *G. breve* and common chemical parameters such as pH, inorganic phosphate, and nitrate-nitrite. It was basically established that *G. breve* did not require much N for growth.

• In addition to their work with waste materials, Doig and Martin (1974) tested inorganic nutrients (orthophosphate, nitrate, and ammonia) and certain detergent components. Individually, the inorganic nutrients did not significantly affect cell populations; but combinations of these nutrients increased populations 3-fold. Also, when the orthophosphate concentration was about 0.10 ppm (a typical value for west

Florida coastal waters) the maximum cell concentration became a linear function of the amount of ammonia N added. This result provided further evidence that inorganic N sources often control the development of *G. breve* blooms. Similar to what had been observed in batch culture studies with *G. breve*, increasing nutrients in the medium extends growth time and therefore leads to higher cell numbers, but increasing nutrients does not increase the growth rate. In this study, growth rates varied from 0.112-0.258 divisions/day depending upon the substance added to the cultures (Note: Three significant figures for a growth rate is unlikely, but as stated in the Methods, the results reported in this paper are as taken directly from the original papers).

• More recent studies have added a few chapters to the nitrogen story. Preliminary results indicate *G. breve's* high affinity for inorganic N, but there are yet no values for uptake and growth rates as a function of nitrate, nitrite, ammonia or urea (Steidinger *et al.* 1997). However, as suggested in work by Baden and Mende (1978) and shown by Shimizu and Wrensford (1993), *G. breve* cell yields increase substantially with the following organic N sources: urea, glycine, leucine, and aspartic acid. In offshore blooms, ammonia is generally only found at about 1-3 μM, and nitrates are even lower so the ability of *G. breve* to use organic N sources in addition to the inorganics is significant for bloom growth and maintenance.

c. Metals and vitamins

Little is known about the microconstituents of seawater that affect the growth of *G. breve*, and the literature on metals and vitamins is particularly confusing. For example, researchers tested a wide array of metals and complexes but they used different methods, metal forms and concentrations. Furthermore, in many cases, metal concentrations were not reported. Following is a chronological discussion of the literature available on metals, vitamins and *G. breve*.

• In one of the first successful attempts to culture *G. breve*, Wilson and Collier (1955) had to add sulfides to a standard aged seawater medium to maintain growth. They also tested a variety of inorganic and organic compounds, vitamins, and natural extracts from soil and fish samples. The soil and fish extracts (which contained vitamin

B_{12}, biotin, thiamine, and other B-complex vitamins) stimulated growth, as did adding a chelator (ETDA•Na). Adding certain trace metals in place of the soil extract (for example, Fe, Zn, Mn, Sr, Rb, Mo, Co, Cu, Cr, Ti, Al, Si, and Zr) supported growth initially, but not for an extended period of time. Metal concentrations were not reported.

• In a multifaceted study using mass cultures of *G. breve* and fish bioassays, Starr (1958) determined the effect of heavy metals on *G. breve's* toxicity. He added Sr, Zr, Hg, Ag, and Cu at final concentrations of 5 ppm. Within 7 min, Hg, Ag, and Cu killed *G. breve* – the guppies, used as the bioassay organism, showed signs of distress within 13-18 min. Zr and Sr were not as lethal – *G. breve* remained active for about one hour, and the guppies did not show signs of distress until well over 2 h. In the control groups (no added metals, just *G. breve*), the guppies were distressed in 2 h, and the number of live *G. breve* cells rapidly declined. The metals that destroyed *G. breve* enhanced toxicity. It is interesting to recall that Wilson and Collier (1955) had found that some metals (including Sr, Zr, and Cu) initially supported growth of *G. breve*, but not for an extended amount of time.

• One year after Starr's report, Wilson (1959) found that *G. breve* needed 3 water-soluble vitamins to grow in artificial medium: thiamine (B_1), biotin (B_3) and cobalamin (B_{12}). Thiamine was the most effective singular vitamin, but thiamine and biotin together worked even better. Wilson also found it impossible to grow *G. breve* in completely artificial medium unless a trace element mixture was added. The precise cocktail of elements was unknown, but he noted Zn, Ti, Zr, Mn and B as potentially important. Copper, Ni, Rb, Mb and Ba also supported better *G. breve* growth on occasion (similar to the results of Wilson and Collier in 1955), and adding Fe never improved growth (regardless of the form and concentration). Wilson also stated, however, that aged seawater or a soil extract served as a suitable replacement for the metal mixture. In Wilson's words,

> "These elements, with the possible exception of Zr, are normally present in seawater, and their absence would probably not be a limiting factor for red tides. The form and higher concentrations of these

elements may be a limiting factor of red tides. We must add metal chelators or metal complexing substances to prepare a suitable seawater medium for *G. breve*, in most instances. Therefore, the occurrence of natural metal chelators or metal complexing substances may be necessary for red tides to develop."

Wilson's results with copper contradicted Starr's (1958) results, but he did not report concentration data; he offered only a very general assessment of his trace element work.

• Aldrich (1962) established that *G. breve* is photoautotrophic: it requires light and carbon dioxide to grow. He tested an array of organic substances as potential energy sources for *G. breve* and found that regardless of the nutrients added, *G. breve* would not grow in the dark. Like Wilson (1959), Aldrich also emphasized the importance of micronutrients such as vitamins, trace metals and chelators in the growth and overall ecology of *G. breve*.

• Wilson (1965) found that a combination of EDTA, a metal chelate, and Fe worked the best to stimulate the growth of *G. breve*. In his earlier work (Wilson 1959) Fe did not stimulate growth, but he had not used a chelator.

• Martin and Olander (1971) investigated the role of the following 3 trace metals in *G. breve* outbreaks: Cu, Ti and Zr. Recall that Starr (1958) tested Cu and Zr, and found them inhibitory to growth, and Wilson (1959) tested Ti and Zr, and found them to stimulate growth if added with other trace metals and a chelator. Martin and Olander considered the growth constant an ideal parameter to study because it reflects the growth rate during the exponential phase of cell growth and was easily reproducible within the control groups. Why did Martin and Olander focus on Zr, Ti and Cu? First, Zr and Ti were found in a 1956 bloom (0.001-0.01% and 0.01-1% of the total dissolved solids, respectively) so their potential role in the outbreak, if any, was questioned. Second, about the same time (Autumn 1957), Cu had been used as a control agent to kill blooms; $CuSO_4$ was sprayed from crop-duster planes over about 16 mi^2 off St. Petersburg, Florida ($CuSO_4$ was a well known classic algicide). Limited field tests were conducted during outbreaks in 1952, 1953, 1954, and 1957. Although these Cu control efforts were unsuccessful (*G. breve* population returned to lethal level within about 2 weeks), more studies on the effect of Cu on *G. breve* would have benefited the research community (perhaps before the dusting was tried in the first place).

Martin and Olander (1971) added stock solutions of the 3 trace metals in triple-distilled water to the culture tubes before autoclaving them for the experiment and used a chelating agent (EDTA•2Na). It is important to recognize that some of these early studies likely had artifacts of sterilization in the glass; nevertheless, results are reported as they originally appeared in the literature. Martin and Olander determined cell counts after removing an aliquot of the medium about every 4-5 days, and found that adding the trace metals generally lengthened the duration of the stationary phase. They also concluded that Ti and Zr generally do *not* stimulate the growth of *G. breve*. The role of these elements in the 1956 bloom remained open to question; Martin and Olander hypothesized that the metals may have come from the decomposition of organisms, the hydrolysis of Fe-complexes from nearby rivers, or from humates which contain Ti, Zr and Fe. They also found the following: the growth constants were inversely related to the cupric ion concentration, Zr did not have an effect on the growth constant, and increasing the Ti concentrations decreased the growth constant. The mean growth rate was 0.19/day.

• Dinoflagellates generally respond favorably to Fe additions. Ingle and Martin (1971) investigated the association of *G. breve* red tide outbreaks with the Peace River drainage of Fe with tannic acid, humic acid and other chelators. They proposed an iron index as a means of predicting blooms, and defined it as "the total amount of Fe potentially delivered to an outbreak during a three-month period." They used data from 1944-1969 in areas from Charlotte Harbor to Sanibel Island, Florida, where the index was 235,000 pounds of Fe delivered by the Peace River (assuming optimal temperatures and the absence of extreme weather such as hurricanes). The index equated to the flow rate of freshwater delivery. Ingle and Martin postulated that outbreaks start in a small area of Charlotte Harbor and spread outward if sufficient Fe-humic acid complexes exist in the surrounding areas. This raised the question of rainfall's role in blooms. (Note: Red tides have occurred off Charlotte Harbor in drought years including 1971, 1979 and 1982, when that flow rate was not reached.)

• Martin *et al.* (1971) analyzed 14 west Florida streams from 1968-1969, and determined the humic acid, Fe, Cu, Mn, and Zn content of surface water samples. (Humic acid is the dark brown macromolecular decomposition product of plant and animal matter; humics are significant because they are natural chelators so they can form complexes with metal ions). They also analyzed riverflow data. The northern streams had uniformly lower concentrations of humic acids and soluble metals than the southern streams; the central streams had intermediate values. Many northern streams, however, can still deliver a considerable amount of humic acids and soluble metals because they have a high stream flow. A linear correlation of humic acid concentration with rainfall and trace metal concentrations existed for all rivers tested. The southern streams had the most significant correlations, which provided more support for the iron index developed by Ingle and Martin (1971). However, the results did not establish that Fe, humic acids, or a combination caused *G. breve* blooms. Martin *et al.* recognized that some other substance(s) associated with iron and humic acid species may play a significant role.

5. **Surfactants**

Surfactants, surface-active agents that can cause seawater to foam, do not promote *G. breve* growth. For a time they had been proposed as a potential means to control localized outbreaks. The following section summarizes the major works published on the effect of surfactants on the growth of *G. breve*.

• Kutt and Martin (1974) studied the effect of 6 surfactants on *G. breve*. They found an inverse relationship between the amount of surfactant added to cultures, and the growth constant and maximum cell number. The surfactant molecule lysed the *G. breve* cell either by breaking down the membrane protein or penetrating the lipid bilayer. *G. breve* is unarmored, so it is susceptible to this penetrative action. The anionic surfactants had the most deleterious effect in terms of response, growth rate, and maximum cell number compared to cationic and non-ionic surfactants. Kutt and Martin did not offer a suggestion as to why this occurred. The surfactant tested with the most favorable rate of degradation was C_{12} alkyl-benzene sulfonate. Contrary to Doig and Martin's study (1974; discussed next), in which they enriched the seawater medium with sewage effluent with detergent, the cells did *not* decline in this experiment with the enriched seawater medium; population levels did decline when they used filtered, autoclaved seawater. Also, the most favorable amount of surfactant was about 12.5 ppb; any higher concentration caused ineffective surfactant micelles to form, so the *G. breve* growth constant and cell number actually increased.

• Doig and Martin (1974) hypothesized that municipal waste materials might increase the intensity and frequency of major *G. breve* outbreaks. Their basic conclusion was that eutrophication might help sustain *G. breve* populations in inshore waters. Adding waste materials to natural water from Juno Beach, Florida significantly increased the maximum cell population (up to three times the controls). Also some detergent component, perhaps the surfactant, killed *G. breve* within 24 h when added at a low P concentration (0.05 ppm P).

• Hitchcock's (1976) master's thesis, completed at the University of South Florida, focused on the effects of temperature and surfactants on *G. breve*. His temperature results are discussed in the Temperature section. Hitchcock used linear alkylbenzenesulfonate (C_{13}LAS), a biodegradable anionic surfactant which is basically a long aliphatic chain with a charged headgroup, and found that at concentrations as low as 0.025 ppm, *G. breve* cell numbers decreased significantly. He concluded that although more studies were needed, C_{13}LAS might be successful in controlling small, localized outbreaks. The fact that bacteria degrade C_{13}LAS relatively quickly highlighted its potential as an advantageous control agent. Hitchcock also observed how the surfactant diffuses through seawater, which has a high ionic strength and enables micelles to form readily. When introduced from the bottom, it diffused upward and spread evenly throughout the column for about 10 days. When introduced from the top, however, it remained at the top; the number of *G. breve* cells at the top therefore declined, but those at the bottom of the column increased. Surfactant concentrations of 26 ppb were lethal to the cultures no matter where it was introduced. Hitchcock listed the following as potential problems with the use of surfactants to control red tide blooms: localized kills of marine organisms, some organisms grow better with small concentrations of surfactant so blooms of other potentially troublesome organisms might result, and the long-term effects of surfactant use are yet unknown.

a. Other

• Paster and Abbott (1970) studied gibberellic acid (GA), a well-recognized plant hormone that influences the activity of almost any plant tissue or organ. When they added about 10^{-7} molar GA to the cultures, the lag time (6-8 days) was shortened or completely eradicated, and the final cell number increased. Concentrations greater than 5×10^{-7} molar GA inhibited cell growth. The study was significant in that while *G. breve* blooms are well known to occur in nature, they are difficult to simulate in a laboratory setting; if GA significantly increases the final number of culture cells as it did in this experiment, Paster and Abbott suggested that it could be a contributing cause of the blooms in nature. The GA could originate from debris of higher-order plants that get washed into the sea, or from other marine algae.

• Baden and Mende (1978) investigated the heterotrophic capabilities of *G. breve*, specifically its response to carbohydrate carbon sources. In doing so, they revisited an issue addressed by Aldrich (1962), who established *G. breve* as a photoautotroph and reported that heterotrophy was not a significant factor in blooms. In Baden and Mende's study, *G. breve* rapidly used exogenous glucose in the light to synthesize cellular components such as amino acids; it did not completely oxidize the glucose to carbon dioxide, and more than half of the radiolabelled glucose was found in amino acids (it is well known that algae synthesize ATP via cyclic photophosphorylation during protein synthesis). The only labeled sugars found in the polysaccharides were galactose, xylose, and arabinose, so Baden and Mende postulated that glucose was not an important component of either structural or storage polysaccharides. Furthermore, the results suggested that a facilitated diffusion transport system was at work; that glucose uptake could be competitively inhibited, dependent upon the concentration, and saturate at high glucose concentrations. Physiologically, this all means that *G. breve* is photomixotrophic. An organism that is truly heterotrophic would continue to grow in the dark and derive its ATP from oxidative phosphorylation, but this was not the case in *G. breve*.

b. Evaluation

If precise knowledge of *G. breve's* growth requirements existed, mitigating and/or controlling Florida red tides would seem a much more approachable possibility. In general, the picture of *G. breve* that emerges from the literature is that it is an adaptable organism capable of utilizing a variety of nutrients in a variety of forms. Researchers have made progress toward understanding *G. breve*'s growth requirements, but the earlier literature especially warrants careful analysis and/or re-analysis. Much of it is riddled with confusion.

For example, it was often unclear what form of N or P researchers measured (dissolved or total), which makes any conclusions drawn by the researcher open to interpretation. The earlier trace metal studies were also hindered by a lack of ultraclean techniques; it was likely that contamination occurred in the experiments thus raising questions about the results. It is also important to consider the activity of the trace metal, not just how much is there. Still further, many times the laboratory and field results do not mesh, which augments the challenge of addressing mitigation/control issues. Perhaps the dynamics of how nutrient availability *changes* assumes more significance than measuring actual concentrations. It was also evident in the literature that many of the studies particularly in the 1970's focused on river input and its role in *G. breve* blooms because it was still thought that blooms started inshore. It is now confirmed, however, that blooms start offshore; more data are needed from the offshore areas in association with blooms. One concluding point is that in order to obtain a clear picture of the nutrient dynamics at work within the *G. breve* cell and *G. breve* blooms, the historical literature base must be reviewed critically and cautiously.

As discussed, tracing the literature about P and its role in *G. breve* metabolism is particularly difficult. Bein's (1957) work undermined the role of P in blooms but Wilson's work kept stirring it up again. The iron story also seems to be left without a satisfactory ending. It is important to address the possible role of the Fe-rich Saharan dust now known to fall over the Gulf of Mexico in the summer and fall months, which meshes with the timing of most *G. breve* blooms (Walsh and Steidinger, in press).

In the oligotrophic nutrient regime of the Gulf of Mexico, the elasticity of *G. breve* makes sense. *G. breve* is a K-selected organism adapted to low nutrient conditions (cf. Steidinger *et al.* 1997). It is significant that no single nutrient limits the growth of *G. breve* at any given time. The *combined* effects of nutrients, along with temperature, salinity and light data are important to grasp if a better understanding of the overall ecology of *G. breve* is the goal. More long-term studies focusing on how the nutrient dynamics of the Gulf of Mexico change with time are needed. The literature suggests that most nutrient measurements are taken during or after blooms, but studies on the ambient nutrient conditions existing before blooms are in order.

It was also interesting that the role of other bloom species such as *Trichodesmium*, a N-fixing cyanobacteria, was first questioned by Chew in 1953. In the more recent literature (that is, the 1970's-1990's), researchers continually questioned the possibly significant role of *Trichodesmium* in *G. breve* blooms. This represents one question that warrants prompt investigation. *Trichodesmium* blooms might also provide *G. breve* with Fe in addition to organic matter. Not much new information about this particular ecological area has been unraveled since the 1950's, yet its potential significance to understanding the dynamics of blooms at large is overwhelming.

Furthermore, understanding the nutrient story gets a bit more interesting and challenging closer to the shelf as the waters are influenced by occasional Loop Current intrusions and coastal drainage. This raises the importance of interpreting nutrient studies on *G. breve* with the physics and geology of the areas where it resides in mind. For example, what about the phosphatic deposits along the west Florida coast? What is their connection, if any, to *G. breve* blooms? Furthermore, it is especially significant to note the lack of knowledge about nitrogen in blooms. Questions like this warrant further investigation and highlight the emerging importance of understanding and embracing the interdisciplinary nature of red tides.

6. Toxinology

a. Structure and toxicity

Gymnodinium breve is one of about 40 toxic phytoplankton species identified to date in the Gulf of Mexico. It is the one that is most notorious for causing dramatic fish kills and human health problems along the west Florida coast. However, relatively little is known about toxigenesis in marine dinoflagellates (Tomas and Baden 1993). The following discussion chronologically addresses the information that has been added to the literature store about *G. breve's* toxinology. Table 4 provides a summary of the information discussed.

Starr (1958) was among the first to describe the biochemical action of *G. breve* toxins on marine fish. He used guppies and mullet as bioassays. *G. breve* densities surpassing 240,000 cells/l caused the fish to die, which refined Ray and Wilson's (1957) earlier report that cultures with 600,000-4,800,000 cells/l were toxic to the several fish species they tested. Starr's estimate remains the generally accepted cell concentration known to be detrimental or lethal to fish (Steidinger 1973; Steidinger and Joyce 1973). Although their physiological responses were similar, the mullet died quicker than the guppies (mullet died within 2-4 min; guppies died within 8-15 min). General responses included the following: violent writhing and cork-screw movements within 30 seconds, contractions and tail curvatures at 10-20 second intervals thereafter, equilibrium loss within 1-2 min, irregular opercular movements, slowed overall response, and occasional bursts of activity before death.

Starr (1958) was also among the first to establish some of the physical properties of *G. breve* toxins. He hypothesized that the toxin is an endotoxin, which means it resides within the cell, and found that exposing *G. breve* cells to temperatures less than 10° C or greater than 37° C rendered them more toxic than the original cultures. Radically changing the pH also increased culture toxicity, as did adding heavy metals such as Sr, Zr, Hg, Cu, and Ag. Adding the metals killed the *G. breve* cells, but presumably enhanced the culture toxicity because the endotoxin was released upon cell rupture.

In the 1950's and 1960's, very little was known about the biochemical properties of *G. breve* toxins. The methodology required for this work did not improve significantly until the 1970's, so many early researchers documented toxinologic information by comparing *G. breve*'s poisonous effects to other dinoflagellates. McFarren *et al.* (1965) were among the first to note similarities between *G. breve* toxins and ciguatera toxins (see also Woodcock 1948). They were also among the first to hypothesize that the *G. breve* shellfish poison was the source of human respiratory and eye irritation reported by beachgoers.

Table 4. Summary of *G. breve* Toxinology

General brevetoxin characteristics

- Large, hydrophobic, cigar-shaped molecule
- Endotoxin (resides within the cell)
- About 30 Angstroms long
- Made of long carbon chains and contiguous ether rings
- Fat-soluble or lipid-soluble
- Very weak acid; acid stable; base labile
- Crude toxin: Photosensitive (inactivated by ultraviolet, visible and infrared radiation)
- Culture toxicity increases when temperature is < 10° C or > 37° C, pH is significantly raised or lowered, or heavy metals are added
- Half life: 0.5 hr at 80° C

Toxin derivatives

- About 10 toxin derivatives are known
- Most commonly studied = Brevetoxins A and B
- Brevetoxin A ($C_{49}H_{70}O_{13}$); also called BTX-A, PbTx-1 or T_{46}
- Brevetoxin A = more potent and more flexible than Brevetoxin B
- Brevetoxin B ($C_{50}H_{70}O_{14}$); also called BTX-B, PbTx-2 or T_{47}
- Brevetoxin B = first to be chemically described (a rigid ladder-like molecule with 11 contiguous fused ether rings)
- Other:
  - A dihydro derivative of brevetoxin; also called T_{17}
  - A chemically reduced form of Brevetoxin B; also called PbTx-9

Physiological action of toxins

- Opens sodium channels and increases permeability of ions across nerve and muscle cell membranes
- Specifically act at neurotoxin receptor site 5 of the voltage-sensitive sodium channel
- Depolarization is dose-dependent; reduces energy required to activate the channel
- The toxin flexes around the binding site and is held in place by hydrophobic interactions and H-bonds - the resulting conformational changes cause the channel to remain open
- Inhibits oxygen consumption at nerve and muscle cell membranes
- Causes massive neurotransmitter release, which in turn causes cardiac arrhythmia, peripheral vasodilation, and dose-dependent depression in the respiratory rate and core body temperature

A few pathologic effects

- Concentrated primarily in liver
- Liver is main route of detoxification
- Increases hepatocyte Na+/K+ ratio
- Eliminated primarily through urine, not feces

Other

- After amino acids are degraded outside the cell, it is hypothesized that they are incorporated into the neurotoxins
- Increases EROD activity in fish (EROD = a hepatic P450 enzyme, key enzyme in biotransformation)

At this time, researchers were much more familiar with ciguatera (tropical fish poisoning) than the *G. breve* poison; in fact, McFarren *et al.* (1965) called *G. breve* toxin "the ciguatera-like poison." They used mouse bioassays to detect red tide toxins in shellfish, a technique pioneered by McFarren, and found the toxin in oysters and clams from Charlotte Harbor, Lemon Bay, Sarasota Bay, and Tampa Bay, Florida. The study was based largely on anecdotal epidemiological information from seven people who had eaten oysters or clams from these areas. Their study also shed light on some chemical and physical properties of *G. breve* toxins. After one of their first attempts to extract the *G. breve* toxin, McFarren *et al.* established the following: the toxin is fat-soluble like ciguatera toxin (ether extract caused death in mice quicker than the aqueous extract); it is a very weak acid; and it is gradually destroyed when heated at an acidic pH (the toxin in meats is not destroyed by cooking).

Sievers (1969) performed comparative study between *G. breve* and *Gonyaulax monilata*, a dinoflagellate species implicated in blooms on Florida's east coast. Sievers confirmed what Ray and Aldrich (1967) suggested two years earlier: although both species cause fish kills, the *G. breve* toxin is distinct from the *G. monilata* toxin. (It is now known that *G. monilata* has water-soluble toxins whereas *G. breve* has lipid-soluble toxins). The fish tested were sensitive to both toxins (especially *Cyprinodon variegatus*), but crustaceans were resistant to both. The annelids and molluscs tested were more sensitive to *G. monilata* than *G. breve*. Sievers' study highlighted the differential effects that *G. breve* toxins have on marine fauna; some animals die directly from the toxin (for example, fish) whereas others such as some molluscs and crustaceans die from oxygen depletion associated with the algal bloom. The study was significant in that Sievers was among the first to question the role algal blooms play in the seasonal population fluctuations evident in the Gulf of Mexico, a vexing research question that lingers today.

Doig and Martin (1972) studied the physical and chemical stability of *G. breve* toxins using fish assays with water samples from a severe 1971 outbreak in Tampa Bay, Florida. Their results indicated the following: *G. breve* toxins are acid stable, base labile, rapidly inactivated at temperatures greater than 70°C, and photosensitive (inactivated by ultraviolet, visible and infrared radiation). The half life of the toxin at 80°C was 0.5 h. These studies used crude extracted toxin, which explains its sensitivity to temperature and light; otherwise, heat or light does not alter the toxin that resides within the cell (that is, toxin that is not crude toxin). Furthermore, the toxin lasts at least 3 weeks in natural and filtered seawater exposed to natural or laboratory ultraviolet light.

Roberts *et al.* (1979) were among the first to closely examine the bioaccumulation of toxins in marine invertebrates. The different species tested exhibited different sensitivities to the toxin, a significant conclusion that Siever's (1969) study intimated about ten years earlier. The differential toxin sensitivity also raised a significant public health concern; organisms not adversely affected by the toxins can accumulate the toxin in certain body tissues which, although not eaten by humans, may still be transferred up the food chain where the effects crystallize within a larger animal that *is* eaten by humans. Roberts *et al.* examined 3 mollusc species and 2 crustaceans from Tampa Bay, Florida. Only the molluscs were adversely affected by *G. breve* endotoxins; the common sign of intoxication was a loss of muscle control (the molluscan shell hung loosely from the foot of the animal). The crabs were fed toxic meat, but the edible portions tested were nontoxic.

In the 1980's and early 1990's, knowledge about the biochemistry of *G. breve* grew much more refined. Each of the studies reviewed assumed a certain level of background knowledge regarding *G. breve* toxinology. *G. breve* endotoxins became known as brevetoxins (lipid-soluble neurotoxins). Brevetoxins are hydrophobic molecules with long carbon chains and contiguous ether rings (Nakanishi 1985). Two main types were known: the more potent brevetoxin A ($C_{49}H_{70}O_{13}$; also called T_{46} based on chromatographic properties) which is active at relatively low concentrations, and brevetoxin B ($C_{50}H_{70}O_{14}$; also called T_{47}).

Attempts to isolate pure brevetoxins from *G. breve* cell cultures were made since 1968, but it was not until 1981 that Lin *et al.* (1981) used x-ray crystallography to describe the chemical structure of brevetoxin B for the first time (a rigid ladder-like molecule with 11 contiguous fused ether rings). The chemistry of brevetoxin A was described in 1986 by Shimizu *et al.* However, literature on the biochemistry of *G. breve* is complicated by the number of names used to describe the various brevetoxin derivatives (See Table 4). The name *G. breve* was once changed to *Ptychodiscus brevis* based on ultrastructural characteristics (Steidinger 1979), so the brevetoxin derivatives referred to throughout the literature were also dubbed "the PbTx series." Researchers occasionally refer to brevetoxin A and B as PbTx-1 and PbTx-2, respectively. In this review, "brevetoxin A and B" will be used where possible for consistency.

Toxinologic studies in the 1980's and 1990's generally assumed a sharper, narrower focus that pinpointed the mechanism of how the toxin acts physiologically. It was known that dinoflagellate toxins, particularly neurotoxins, affect the voltage-sensitive Na+ channel in the plasma membrane of nerve and muscle cells in different ways. Brevetoxins alter the way Na^+ channels function. Studies on the squid giant axon showed that brevetoxin causes the membrane to fire repetitively (Westerfield *et al.* 1977) by increasing the flux of Na+ ions into the cell. Brevetoxins also increase the frequency of action potentials in the crayfish nerve cord (Parmentier *et al.* 1978), cause acetylcholine release from nerve endings, and depolarize skeletal muscle (Gallagher and Shinnick 1980).

Nakanishi (1985) published an informative review of brevetoxins. He focused on the chemistry of brevetoxin B but mentioned all three of the pure brevetoxins known to researchers at the time (brevetoxin A, B, C; lethal doses 3 ng/ml, 16 ng/ml, and 60 ng/ml, respectively). ^{13}C-NMR and ^{1}H-NMR spectra showed that brevetoxin A has a different skeleton than brevetoxin B or C. Brevetoxin B molecule has an unprecedented structure: it is flat, stiff, ladder-like, about 30 Angstroms long, and comprised of trans-linked rings, one lactone, and ten ether rings. However, this molecule acts to open Na+ channels and increase permeability of ions across nerve and muscle cell membranes remained unknown.

Catterall (1985) reviewed the literature on all extant dinoflagellate neurotoxins and how they interact with different sites on the channels. His review of brevetoxins A and B started answering some of the questions that Nakanishi's review asked. Catterall suggested that brevetoxins act at a site known as neurotoxin receptor site 5. At the time, this was considered a new receptor site, and was eventually called an "orphan receptor" (Rein *et al.* 1994) because no known endogenous biological molecule binds naturally to it. Catterall (1985) also proposed that brevetoxin A, the most potent toxin derivative, increases Na+ permeability by reducing the energy required to activate the channel.

Huang and Wu's (1985) study provided more specific information about how brevetoxin B acted at Na+ channels using crayfish and squid nerve axons. They specifically used T_{17}, another name for the dihydro derivative of brevetoxin. Applying 1 µg/ml T_{17} internally or externally to the axons initiated a depolarization of 30 mV by increasing the Na+ permeability of the resting membrane. It took 30 s to reach the 30 mV, and the depolarization lasted for 30 min. The extent of the depolarization was dose-dependent. In short, Huang and Wu's study showed that T_{17} induces a Na+ current with relatively slow kinetics (Na+ currents generally work fast); it causes depolarization by opening the channels at large negative potentials, in a range where Na+ channels normally do not open.

The unusual and complex structure of brevetoxins often deemed attempts to synthesize them rather frustrating. Chou and Shimizu (1987) were among the first to partially perform the biosynthesis of brevetoxins. Brevetoxin A and B have different ring structures but the last four rings on each molecule are similar, which suggests a similar biosynthesis. Chou and Shimizu performed labeling experiments, reexamined ^{13}C NMR data from earlier studies, and hypothesized that brevetoxins represent a new type of mixed polyketide formation involving dicarboxylic acids in which a Claisen-type condensation occurs on the second carboxylic functional group, and another carboxyl group is lost (polyketide biosynthesis = condensation of acetate units with the methyl groups originating from either S-adenosylmethionine or propionate).

Lee *et al.* (1989) expanded upon the biosynthetic studies of Chou and Shimizu (1987). They diagrammed the biosynthesis of brevetoxin A and B in full detail, and concluded that the structures of these polyoxygenated single carbon chains resemble the polyether ionophores from terrestrial microorganisms (for example, polyether antibiotics such as those produced in the genus *Streptomyces*). They reiterated what Chou and Shimizu (1987) found; the evidence suggested the synthesis of brevetoxins occurs from mixed polyketide origin rather than from a simple polyketide origin. The evidence also suggested a unique participation of carbon dioxide (CO_2) in the synthesis of the two brevetoxins, as well as an unusually high degree of the citric acid cycle in the synthesis of these secondary marine metabolites; this may signify an important difference between terrestrial and marine microorganisms.

Shimizu and Wrenford (1993) confirmed that the biosynthesis of brevetoxins follows a path unlike any biosynthetic pathway in analogous terrestrial polyether compounds. They found that the growth of the dinoflagellate and its toxin production are greatly influenced by certain amino acids, which are incorporated into the neurotoxins after being degraded by the organism. Shimizu and Wrenford proposed that the amino acid degradation occurs outside the cell, and generally concluded that amino acid metabolism plays a key role in forming secondary metabolites in dinoflagellates. In an earlier study by Baden and Mende (1978), more than half of the radiolabelled glucose taken up by the cells was found in amino acids.

Up to this point, 9 or 10 different toxin derivatives were known to be associated with *G. breve*. Roszell *et al.* (1990) described these derivatives, along with the cell culture stages in which each occurs. They postulated that toxin profiles change according to the metabolic events occurring within *G. breve* at a given time. In any new culture, the natural form of the toxin found is an aldehyde. As the culture ages, however, other more water-soluble and easily excreted toxins are derived from the aldehyde function. Schulman *et al.* (1990) isolated a ninth toxin derivative: a new polyether toxin which they called PbTx-9. It was a chemically reduced form of PbTx-2, or brevetoxin B. PbTx-9 was isolated from *G. breve* cultures in the stationary or declining phase of development. The study's significance lies in the fact that the quantity and type of toxins change with the age and growth stage of the cell culture used.

Other studies in the 1990's focused on how brevetoxins affect animals physiologically. Edwards *et al.* (1990) used radiolabelled brevetoxin to test the binding of the toxin to brain tissue from three phylogenetically distinct vertebrates: the rat, the turtle, and the fish. The rat brain synaptosomes had the most binding (probably more regions to bind), but the binding was similar in all cases, which suggested that the conformation of the region around the voltage-sensitive Na+ channel has been conserved over evolutionary time. Edwards *et al.* concluded that the toxicity of the lipid-soluble neurotoxin had the same effect and degree of toxicity on the brain tissues.

Numerous West Indian manatees (*Trichechus manatus*) and bottlenose dolphins (*Tursiops truncatus*) died from brevetoxin-related intoxication in the 1980's and 1990's. Cattet and Geraci (1993) took the first step toward understanding the pathologic effects of ingested brevetoxins (PbTx) in marine mammals. Rats were used as test animals, and the brevetoxin concentrated primarily in the liver even though it was widely distributed. Also, the animals eliminated most of the brevetoxins in urine rather than feces, which contradicts the conclusion by Poli *et al.* (1990) that the feces were the primary route for brevetoxin detoxification. Poli *et al.* had administered the toxin to their laboratory animals parenterally, however, whereas Cattet and Geraci based their pathologic studies on oral ingestion, which they contend mimics the more natural route of exposure.

Other studies in the 1990's focused on improving the methodology used to better understand the biochemistry of *G. breve*. These studies are significant because our understanding of how this organism functions is only as good as the methods used. (A more detailed discussion of the evolution of methodology is found in the next section). In the case of *G. breve*, immunoassays have long served as a primary tool to study the biochemistry and binding of brevetoxins. The primary goal in immunoassay production is to have a relatively broad specificity to an immunogen, but not too broad; for example, a good antibody would bind to brevetoxins, but not to all toxins with polyether backbones (there are many). Baden *et al.* (1988) were among the first to produce goat antibodies to brevetoxins. Levine and Shimizu (1992) confirmed what earlier studies hypothesized: despite some similarities between brevetoxin A and brevetoxin B, their structural backbones are distinct. Levine and Shimizu used a different immunogen to produce rabbit antibodies to brevetoxin B, and the antibodies reacted with brevetoxin B at least 500 times more effectively than with brevetoxin A.

Gawley *et al.* (1992) performed a conformational analysis of brevetoxin binding using models. They compared brevetoxin to ciguatoxin, a relationship first suggested by McFarren *et al.* (1965). Brevetoxin and ciguatoxin have different carbon backbones, but they bind to the same site 5 of the voltage-sensitive Na+ channel in nerve and muscle membranes. Gawley *et al.* hypothesized that the flexibility of the carbon backbone, or binding affinity, is related to the relative toxicities of the neurotoxins. Ciguatoxin was the most potent, followed by brevetoxin A and brevetoxin B. Common features of the three neurotoxins included: trans/syn stereochemistry along the entire carbon backbone with oxygen atoms alternating between the top and bottom; each ether oxygen constitutes a one-atom bridge between adjacent rings; and the two brevetoxin backbones have lactone functions on one end, with an enone or alcohol function on the ether. Ciguatoxin and brevetoxin A were more flexible than originally described for the rigid ladderlike structure of brevetoxin B (see Lin *et al.* 1981); they have increasing numbers of torsional rotations, which suggests a relationship between conformational flexibility and toxicity. Gawley *et al.* hypothesized that the toxins interact with the Na+ channel in the following way: 1. the toxin flexes to wrap around or into its binding site, and is held in place by hydrophobic interactions and H-bonds, and 2. the resulting conformational changes might cause the channel to open, which could then be held open by conformational restrictions.

The year 1994 was especially productive regarding for the toxin literature. Rein *et al.* (1994a) did a conformational analysis of brevetoxin A, which has 48 known conformers. They offered a molecular view of site 5 on the Na+ channel where brevetoxins A and B and ciguatoxin bind, and hypothesized that the ligand (toxin) is a 30-Angstrom-long cigar-shaped molecule bound to the receptor (sodium channel site 5) by hydrophobic and nonpolar forces which involve the use of H-bonds near the lactone carbonyl on the receptor molecule. Rein *et al.* also suggested that brevetoxin A is much more flexible than brevetoxin B, but both compete for the same site on the Na+ channel receptor. The toxins measure roughly the same length, and both have straight and bent conformations available.

Rein *et al.* (1994b) further examined the way brevetoxin binds to the Na+ channel by studying 5 naturally occurring, and 7 synthetically modified derivatives of brevetoxin B. Using the mosquito fish as the test species, they found that when brevetoxin binds: 1. the activation voltage required for the channel to open shifts to more negative values (that is, the channels open at normal resting potential), and 2. the channels remain persistently active and open because the bound brevetoxin inhibits inactivation of the opened channels. Also, the strength of the binding is greatest when brevetoxin B is in the boat-chair conformation. Any molecular change that occurs to change this conformation results in a loss of binding efficiency and therefore, a loss in brevetoxin toxicity.

Trainer *et al.* (1994) further characterized the brevetoxin binding domain by photolabelling rat brain sodium channels. Neurotoxins interact with at least 5 receptor sites on the sodium channel, 4 of which reside on a part called the alpha subunit. There are 3 glycoprotein subunits in the voltage-sensitive sodium channel: 1. the alpha subunit which has 4 domains, each of which has 6 transmembrane segments designated S1-S6, 2. the ß1 subunit, 3. and the ß2 subunit. The specific segments of the sodium channel associated with brevetoxin binding are the transmembrane segments called IS6 and IVS5 in the alpha subunit on site 5.

There are at least 10 naturally occurring brevetoxin derivatives belonging to two structural classes, brevetoxin A or PbTx-1, and brevetoxin B or PbTx-2 (Shimizu *et al.* 1986; Lin *et al.* 1981). Melinek *et al.* (1994) induced two goats to develop antibodies to PbTx-3, and identified the following epitopic regions of the molecule: 1. A-ring lactone, 2. K-ring side chain, and 3. H-ring. The A-ring lactone and the H-ring seemed to be the most important antigenic determinants recognized by the specific IgG class of antibodies in goats, whereas the K-ring side chain played a minor role. This type of epitope characterization is significant for the development of various assays.

By this time, it was well known that brevetoxin caused membrane depolarization and massive neurotransmitter release, which in turn causes symptoms including cardiac arrhythmia, peripheral vasodilation, and dose-dependent depression in the respiratory rate and core body temperature. Rodriguez *et al.* (1994) examined the effect of PbTx-3 on hepatic metabolism. They concluded that the toxin-induced effects on the liver are similar to those observed in excitable nerve and muscle tissue. Brevetoxin inhibited oxygen consumption by about 25%, and increased the hepatocyte (liver cell) $Na+/K+$ ratio by about 72%.

How animals metabolize and excrete brevetoxin was unclear at this point. Washburn *et al.* (1994) studied the metabolism of brevetoxin in the gulf toadfish. They administered radioactive brevetoxin and found the greatest percentage of radioactivity in the hepatobiliary system (40%). The hepatobiliary system played a key role in the metabolism and excretion of brevetoxin in fish (kidney and gills played a secondary role; <5%). The muscle tissues and gastrointestinal tract contained 27% and 25% of the radioactivity, respectively. (The three sites together constitute the key sites of metabolism, storage, and excretion). Washburn *et al.* also determined the effect of brevetoxin on xenobiotic metabolizing enzymes. They used immature redfish and two hepatic P450 enzymes called ethoxyresorufin *O*-deethylase (EROD) and pentoxyresorufin *O*-depentylase (PROD). EROD, a key enzyme involved in biotransformation, often increases in response to polycyclic aromatic hydrocarbons. At higher doses (2.5 µg brevetoxin/ 100g body weight), the brevetoxin did significantly increase EROD activity.

In a two-study series, Nicolaou *et al.* (1994, 1995) reported the total synthesis of brevetoxin B, which has 11 trans-fused rings and 23 stereocenters. Recall that brevetoxin B was first structurally described in 1981 by Lin and others.

b. Evaluation

Great strides have been taken in brevetoxin research in the past 30 years. The most significant source of confusion in the early literature was the way different researchers named brevetoxins. Nevertheless as the methodology grew more sophisticated, so too did the knowledge about *G. breve*; the biochemical studies discussed grew more detail-oriented over time. For example, within about 15 years, it was found that brevetoxins acted specifically on the transmembrane segments called IS6 and IVS5 in the alpha subunit on site 5 of the voltage-sensitive sodium channel (VSSC). Toxinological analyses reside within a research niche that is unique, significant and acutely focused. Biochemically related studies about how toxins enter cells are undoubtedly significant to pursue.

7. An Evolving Methodology

The methods used to study *G. breve* and its associated toxins have come a long way since researchers began culturing the organism in the late 1940's and 1950's. Challenges continue to present a bumpy ride on the road to a successful methodology. It is important to have a basic understanding of how various methods have evolved because much of what is known about *G. breve* and its associated brevetoxins is only as good as the methods available. The following discussion provides a sketch of how methodology changed over time. It is broken down into 2 main sections: culturing and brevetoxin analysis.

a. Culturing

i. General information

Studying autecological relationships in the laboratory to understand phyto field dynamics has always presented a formidable challenge (Collier *et al.* 1969). Dinoflagellates in general are extremely difficult to culture (Guillard 1985) and *G. breve* is no exception (Brydon *et al.* 1971). Nevertheless in order to understand the many physical and biological factors at work in red tide blooms (for example, current and wind regimes, variable light and temperature conditions, physical fronts, patchiness), isolated laboratory experiments must be performed and refined using cultured organisms.

Researchers attempted to culture phytoplankton as early as 1871 but the first successful dinoflagellate culture was not achieved until 1908 (Keller and Guillard 1985). Culturing techniques for marine species were developed in the 1930's and 1940's; cultures of *G. breve* were not successfully maintained until the late 1940's and 1950's. *G. breve* is much more difficult to culture than many other dinoflagellates because the athecate dinoflagellate is extremely sensitive to unfavorable conditions such as turbulence and contamination (Collier *et al.* 1969).

A comprehensive review of general phytoplankton culture methods is found in Guillard (1985). The *G. breve* cultures maintained for various studies such as toxin extraction are typically unialgal, but not axenic (Baden 1983). Also, temperature and salinity are not critical factors in culturing *G. breve*; the optimal salinity varies between 27-37 PSU, optimal temperature varies between 15-30° C, and light intensity exceeding 200 ft-candles typically does not limit growth (Brydon *et al.* 1971). Culturing takes place in a temperature-controlled room illuminated with cool-white fluorescent lamps (about 40 watts), or a combination of warm white and daylight to provide wavelengths closer to sunlight (Heil 1986). NH-15 medium (S=32 PSU) is generally preferred, but many variations exist (Wilson 1965; Collier *et al.* 1969). Also, an initial inoculum of 1×10^6 cells/l generally means that cultures will grow to a maximum density of about $2\text{-}4 \times 10^7$ cells/l in 17 days (Baden and Mende 1978). Steidinger used an initial inoculum of 2×10^6 cells/l, and it would take 21-28 days to reach maximal densities.

Three main types of *G. breve* culture systems exist: batch systems, semi-continuous systems, and large-tank systems (Brydon *et al.* 1971). In classical batch systems, nutrients are added to the medium initially, which supports maximal growth rates until nutrient depletion occurs. In semi-continuous culture systems, a constant fraction of the culture is exchanged with new, nutrient-enriched media each day. The exchange rate is designed to maintain a relatively constant growth rate (usually expressed as % per day). The large tank culture systems, such as those used by Cummins and Stevens (1970, cited in Brydon *et al.* 1971), can support populations up to 1,900 cells/ml in a 2,000-l heavy-wall polyethylene tank.

The limitations of these systems warrant discussion. Three main differences exist between laboratory cultures and field experiments: 1) rarely would *G. breve* be in a closed sheltered environment, 2) rarely would nutrients be readily available to sustain and promote growth at maximum rates, and 3) rarely in nature would unialgal or predator-free conditions exist. Many are wary of the classical batch systems because the system is static, not dynamic, and does not mimic the natural environment. However, others point out that batch cultures have the same phases or developmental sequences as blooms: seed stock or inoculum, lag phase, growth phase, stationary phase, and death phase. The semi-continuous systems are closer to the pelagic environment where growth rates remain relatively constant, but they still fail to accurately portray the daily and seasonal dynamics of a natural environment. Brydon *et al.* (1971) suggested 2 general rules of thumb: 1) batch culture studies should be used only to study physiological responses to physical parameters such as temperature and salinity, and 2) semi-continuous cultures should be used to study the effects of nutrients on *G. breve* growth (in the presence of bacteria).

ii. Culture research

Wilson and Collier (1955) were the first to report preliminary notes on the culturing of *G. breve*. They were one of the first to define a suitable medium for *G. breve* cultures. Drawing from their experience culturing *Gymnodinium sanguineum (G. splendens)*, they used a base medium composed of aged seawater from the Gulf of Mexico (36.5 PSU; 26-28° C; pH 8.1-8.2), vitamin B_{12}, and Van Niel's medium for sulfur bacteria (diluted 1,000 times). The cultures usually reached maximum growth in 6 weeks; some reached 2,000,000 cells/l. Fish bioassays proved culture toxicity. Sulfides had to be added to the aged seawater medium to maintain growth. After preparing the standard medium, they tested a variety of inorganic and organic compounds, vitamins, and natural extracts from soil and fish samples. The soil and fish extracts stimulated growth and certain trace metals in place of the soil extract supported growth initially, but not for an extended period of time. Ethylenediamine tetraacetic acid (EDTA•Na), a well known chelator, also supported growth.

Since Wilson and Collier's initial work, many variations in the culture media of *G. breve* have been developed. Media can be grouped into two main types: enriched seawater, which is often more convenient to use; and synthetic media, which was first introduced by Aldrich and Wilson (1960), and later modified to NH-15 by Wilson (1965). If aged seawater is used, it should be stored in the dark for a couple months, filtered and after enrichment, autoclaved, and have a final pH of about 7.8 +/- 0.1 (Brydon *et al.* 1971). [Media examples: 1) B-5 medium: Wilson 1965, Brydon *et al.* 1971 2) NH-15: Wilson 1965, Collier *et al.* 1969 3) f/2: Guillard 1975 4) K: Keller and Guillard 1985 5) L1: Guillard and Hargraves 1993].

Wilson and Collier (1955) also emphasized the importance of sterility and cleanliness in *G. breve* culture preparation. They cleaned their glassware numerous times and sterilized it via autoclaving for 30 min 3 days in a row to avoid contamination. Growth also improved when cultures were inoculated about 4 days after the sterilization procedures. Brydon *et al.* (1971) updated and outlined these preculture cleaning procedures in greater detail; they also emphasized the need for scrupulous cleaning in all phases of the culturing process to minimize trace metal contamination. Using high quality reagents, triple-distilled water, and a chelating resin such as Chelex-100 (sodium form) generally limits impurity problems. Glassware should be rinsed with hot tap water, soaked in hot detergent solution, rinsed again with hot tap water, rinsed with distilled water, and finally rinsed with triple-distilled water. Brydon *et al.* (1971) also recommended autoclaving culture tubes filled with triple distilled water for 15 min at 15 psi (longer times are recommended for carboys in larger culture systems), and storing glassware in an oven at 130° C. Wilson had also recommended these cleaning procedures after determining other sources of *G. breve* culture contamination: glue for the liners in tube cages and phenol in the caps, and organics in the deionized water.

The next significant advance in *G. breve* culture research came almost 15 years after Wilson and Collier's study. Collier *et al.* (1969) worked with 6640 individual cultures. This work started in 1956; Wilson (1965) reported some of the early results in *The Florida Board of Conservation Professional Papers Series Number 7.* The primary goal was to find a suitable media for *G. breve* by assaying various natural waters; perhaps then they would be better able to predict blooms based upon the type of water in a given Gulf location. Collier *et al.* (1969) were reportedly the first to use *G. breve* cultures grown in the NH-15 media mentioned earlier. They tested 5 different combinations of river water samples (river samples from all Florida rivers except the Suwannee, Ochlocknee, and Apalachicola), and 8 or 10 combinations of seawater samples from different seasons and locations. Results indicated that sulfides, natural chelators, N, and P all contribute to *G. breve* blooms, and the best results were obtained with the enhanced natural seawater media. River water also stimulated growth. A seasonal effect was noted; cultures with water collected from the late summer and early fall months showed greater growth. Although it was not confirmed at the time, this is consistent with the generally accepted trend that most red tide blooms occur during the late summer and early fall months (Steidinger *et al.* 1997).

iii. Evaluation

The work of Wilson and Collier (1955), Collier *et al.* (1969), and Brydon *et al.* (1971) offer a snapshot of how *G. breve* culturing methods were developed. Wilson and Collier's work can be considered the breakthrough work for culturing *G. breve.* Culture research has come a long way since that time; while *G. breve* was thought to be notoriously difficult to culture, modern techniques make long term maintenance of cultures less tedious. Cultures have been known to last up to two years without additions (not axenically). The important point is to realize that good culture techniques are essential to understanding *G. breve* metabolism with different temperature, salinity, light and nutrient requirements. As mentioned earlier, however, many variations on the proposed methods exist. *G. breve* can tolerate a wide range of conditions so it is important to determine which culture method is the best to obtain the information sought. The questions asked typically dictate the methods used. It is critical that the limitations of any method be understood so the results are correctly interpreted.

b. Brevetoxin Analysis

Most of the methods used to chemically characterize brevetoxins and elucidate their subcellular dynamics were developed in the 1980's. Tremendous advances have been made in this area of *G. breve* research within a relatively short time. Chemically characterizing brevetoxin was challenging for several reasons: it was difficult to obtain enough toxin for testing, the toxin was difficult to purify, there was often interference from other organic substances, and tremendous variations in methodological procedures made the results difficult to compare (Pierce *et al.* 1985).

All dinoflagellate toxins act on excitable cells (cf. Wu and Baden 1985). Excitable cells include nerve (conduction), muscle (contraction), and secretory (secretion) cells. (Recall: *G. breve* excites voltage-regulated Na^+ channels in nerve and muscle cells.) Binding is the initial pharmacological event that signals the onset of toxicity (cf. Wu and Baden 1985), and most brevetoxin analyses have been based upon this characteristic trait. Poli *et al.* (1985) confirmed that brevetoxin specifically binds to site 5 of the voltage-sensitive sodium channel.

There are 4 main types of brevetoxin analyses: 1) those based on the response of a whole living animal to the toxic effects elicited by the compounds (mouse bioassay), 2) tissue cell bioassays, 3) those based on the unique biochemical properties of the compounds (radioimmunoassay, enzyme-linked immunosorbent assay, receptor binding assay), and 4) those based on chromatographic analyses (thin-layer chromatography, high-performance liquid chromatography, high-performance liquid chromatography-electrospray ionization mass spectrometry). Table 5 describes the methods and Table 6 lists their pros and cons. Following is a brief discussion of each method. (Note: For a discussion on micellar electrokinetic capillary chromatography and laser-induced fluorescent detection of brevetoxins, the reader is referred to Shea, D. 1997. Analysis of brevetoxins by micellar electrokinetic capillary chromatography and laser-induced fluorescent detection. *Electrophoresis* 18: 277-283.)

Table 5. 3 Methods of Brevetoxin Analysis

1. **Based on the response of a living organism to the toxin**
   * Both screen food meant for human consumption

   a. *Mouse Bioassay*

   b. *Tissue Culture Bioassay* - toxins perturb normal membrane properties of mouse neuroblastoma cells

2. **Based on the unique biochemical properties of the compounds**

   a. *Biochemical Immunoassay Analysis*

      1. **Radioimmunoassay (RIA)** - counts the gamma-ray emission of radioactive products produced by specific antibody responses towards *G.breve* toxins

      2. **Enzyme-linked Immunosorbent Assay (ELISA)** - measures absorbance changes (visible region) resulting from the formation of complexes due to brevetoxin antibody reactions with peroxidase-linked coenzyme

   b. *Based on pharmacologic activity of the toxins*

      1. **Receptor Binding Assay -** quantifies the binding of toxin molecules to nerve membrane fragments on rat brain synaptosomes; toxin binds to a specific site on the Na+ channel

3. **Chromatographic Analysis**
   * Usually with UV detection
   * Identification is based on matching component mobility (retention) with that of a standard

   a. *Thin-layer Chromatography (TLC)*
   b. *High-performance Liquid Chromatography (HPLC)*
   c. *High-performance Liquid Chromatography-Electrospray Ionization Mass Spectrometry (HPLC-ESMS)*

Table 6. Pros and cons of the methods for brevtoxin analysis.

Pro	**Con**
1. Mouse Bioassay	
a. Only FDA-approved method	a. Slow method, takes at least 3 days for meat extraction, acclimation and hydration of shipped mice, and a 6 hr observation period
	b. Failure to note adverse responses of test animals
	c. Use of live whole animals
2. Tissue Culture Bioassay	
a. Can distinguish brevetoxin from saxitoxin	a. Cannot distinguish between individual toxins
b. High sensitivity; detection limit is 2 ng for PbTx-3	b. Takes at least 4-6 hr to do analytical procedures
3. RIA	
a. Quick, sensitive	a. Cross-reacts with all brevetoxins and ciguatoxins
b. Costs less than mouse bioassay	b. False-positives
4. ELISA	
a. High sensitivity	a. Can usually detect only one compound or one class of compounds in each determination using a specially prepared antibody
b. High selectivity	
5. Receptor Binding Assays	
a. The toxin binds to a specific site on the Na+ channel	a. Lacks specificity (similar to RIA in this way)
	b. Synaptosome preparation is inherently unstable, so fresh tissue must be prepared daily
6. TLC	
7. HPLC	
a. ng/µL sensitivity	a. Subject to interferences from coeluting species
b. Can separate and detect a series of toxins in a single run	b. Limited structural information is provided for unknown compounds
8. HPLC-MS	
a. Subpicomole detection limits	a. Expensive
b. High detection specificity	b. No field application
c. Coeluting compounds more readily detected and possibly identified with mass spectral information	

i. Mouse bioassay

Success in toxinological research depends upon the development of rapid, sensitive, specific assays (Steidinger and Baden 1984) to hasten studies on the rates of accumulation or depuration of brevetoxins in various marine vectors. This information is crucial to understand the ecology of *G. breve* (Baden *et al.* 1984). Effective assays are also important from a public health standpoint; toxin-containing shellfish must be monitored as quickly as possible (Baden *et al.* 1988).

The mouse bioassay is the most commonly used method to monitor shellfish toxins for public health concerns (cf. Hurst *et al.* 1985). It had been used extensively since the 1930's and 40's to study other types of marine toxins such as paralytic shellfish poisons and puffer poison. McFarren (1966) was the first to report how it could be used to study *G. breve*. The basic method has been revised a number of times, and the most recent detailed description of the method can be found in Steidinger and Penta (1999). Mice weighing about 20 g are used. Shellfish meats are homogenized and the poison extract (1 mL) is injected intraperitoneally into the hind leg of each mouse. Toxicity is measured in mouse units (MU) where one MU is equivalent to the amount of crude toxin in 1 mL of extract that kills 50% of the test mice in 15.5 h (Steidinger and Penta 1999). The mean MU/100 g shellfish meat is determined based on a known relationship of dose to death time and the weight of the mice inject with brevetoxins from the shellfish.

When McFarren (1966) first reported this methodology, the toxin detected in Florida shellfish was simply known as "ciguatera-like poison"; it was not definitively known that *G. breve* was the lipid-soluble source of the toxin (Eldred *et al.* 1964 performed another preliminary study relating *G. breve* counts to shellfish toxicity). In another study, McFarren *et al.* (1965) further defined the similarity between the *G. breve* toxin and ciguatoxin *G. breve* toxin was detected in oysters and clams from Charlotte Harbor, Lemon Bay, Sarasota Bay, and Tampa Bay. Shellfish beds were temporarily closed, and a shellfish testing program was started. An epidemiological study showed that 400 to 500 MU of the poison caused mild human illness, and as little as 50 to 80 MU elicited some symptoms of toxin poisoning.

Spikes *et al.* (1968) concluded that cell counts must be used with caution when estimating the lethality of *G. breve* cell cultures. They also found the standard LD_{50} concept preferable to the mouse unit concept (LD_{50} being the amount of toxin necessary to kill half of the mice injected). They cultured *G. breve* in two types of artificial media, NH-15 and NT-33, and looked at 10 different cultures that varied in age, cell concentration, and medium composition. After injecting the mice, ;variation occurred in the death times depending on the age of the culture, concentration, and medium composition. For example, after 0.1 ml of extract was injected in some mice, the death times varied from 19-50 min; and with the 0.5 ml dose, death times varied from two to 12 min. A statistically significant relationship existed between lethality and cell counts in the NH-15 media. Also, the older cultures reached the LD_{50} at lower population levels than younger cultures, presumably due to maturation, disintegration, and death of the cultures with time. Direct measurements of toxin during the stationary and exponential phases of growth are now available (Baden and Tomas 1989; Pierce et al. 1990).

The mouse bioassay is the standard test used in neurotoxic shellfish poisoning (NSP) outbreaks (Steidinger *et al.* 1997) and is the only FDA-approved method. Nevertheless, there are limitations of this assay. While the mouse bioassay is relatively specific and sensitive at 10-20 MU (4-5μg brevetoxin/100g meat = 1 MU/100g meat), intraperitoneal and intravenous injections of brevetoxin have roughly equivalent potencies, which signals a methodological limitation (Steidinger and Baden 1984; Baden and Mende 1982). Researchers may also fail to note adverse responses of the mice if the mice are insensitive to small quantities of the toxin. Cost is another limitation; each mouse costs about $2.40 (Florida Fish and Wildlife Conservation Commission).

Another assay is the ouabain-veratridine dependent cytotoxicity assay, a semi-quantitative method that colorimetrically detects brevetoxins and ciguatoxins and is used in tandem with the mouse bioassay method (Steidinger and Penta 1999). Furthermore, Martin *et al.* (1972) introduced a supplemental method to assess shellfish toxicity: a hemolytic assay that used oyster extracts. It was quicker and easier to use than the mouse bioassay. Although the study did not uncover new information about the biochemistry of *G. breve* toxins, it signified a problem that still exists - the need for an easier method of toxin analysis during a red tide outbreak when the decision to close shellfish harvesting areas must be made as quickly as possible. An accurate field kit that is approved by the Food and Drug Administration is needed.

ii. Purification techniques

There are at least 9 brevetoxins (Hua *et al.* 1995) which can be divided into two types: hemolytic and neurotoxic (Baden 1983). *G. breve* produces more of the latter (Baden 1983), and most researchers have concentrated on this fraction because it can cause neurotoxic shellfish poisoning (NSP) in humans. Early brevetoxin analyses were limited because it was difficult to obtain the pure form of the neurotoxic fraction (Baden *et al.* 1981); as a result, toxicity was often underestimated in the different assays tested. The mouse and fish bioassays, for example, determine overall toxicity but fail to distinguish between the various toxins. Baden *et al.* (1981) also suspected that brevetoxin loses toxicity during storage, which also caused problems in the early purification attempts and brevetoxin analyses. (Note: The current method of storage is under N_2 at a temperature around –80° C.) In general, many purification techniques have been tried, but much of the early data on the toxins is vague and confusing because methods, results, and naming of the toxins differed from laboratory to laboratory (cf. Baden 1983; Shimizu 1978; Alam *et al.* 1975). Thin-layer chromatography (TLC) and high-performance liquid chromatography (HPLC) are often used in tandem to purify brevetoxin fractions. Pierce *et al.* (1985) described the TLC and HPLC techniques for brevetoxin purification in detail. Both methods result in similar elution patterns.

Baden's group at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) contributed significantly to brevetoxin research. In a 1983 review, Baden also cited Trieff and co-workers (1975) in Texas as instrumental in the initial purification of *G. breve* toxins. Trieff's group identified five of *G. breve*'s toxic components using thin-layer chromatography (TLC), which can be used to purify brevetoxin to a crystalline form. Baden named two of the toxins based on observed TLC R_f values: T_{17} corresponds to the alcohol, the minor component (GB-3); and T_{34} corresponds to the aldehyde (BTX-B) (cf. Pierce *et al.* 1985).

Risk *et al.* (1979) also published one of the early reports about purifying active *G. breve* toxins using TLC and HPLC. They started out with a crude ether (lipid) extract of

G. breve, which they successively fractionated into purer compounds. Initial separations were made on silica gel TLC plates and the following eluting solvents: benzene, ethyl acetate, methanol, and water. The most toxic fraction from each step was subjected to other chromatographic procedures that culminated in HPLC and reverse phase HPLC (see Pierce *et al.* 1985 for detailed description of reverse phase HPLC). Seven peaks were detected using both methods (TLC and HPLC), but only the last two peaks were the toxic fractions: two pure white solid compounds they called T_{46} and T_{47}. Both are toxic to fish and mice. T_{46} is the same as Baden's T_{17}, and T_{47} is the same as T_{34} (Baden 1983).

The TLC procedure is also described in the paper by Baden *et al.* (1981). They purified T_{34} (the major brevetoxin) to a colorless crystal that could be stored in a moisture-free environment without losing toxicity. Using chloroform, they extracted the toxin from cultures, flash-evaporated the chloroform fraction, redissolved the residue in methanol, and extracted the toxin again with three portions of petroleum ether. The semi-purified toxin was subjected to the following three silica gel chromatographic procedures to obtain pure toxin: a dry column procedure, which yielded a toxic fraction called IVa; a preparative thin-layer chromatographic step, which yielded T_{34} and T_{17}; and a final thin-layer chromatographic step, which yielded pure T_{34}. After this final chromatography, T_{34} was visible on a fluorescent plate under short-wave ultraviolet (u.v.) light. Baden *et al.* (1981) scraped the u.v.-absorbing band from the plate, eluted the toxin with acetone, evaporated the acetone with N, and precipitated T_{34} from ethanol solution. The precipitate was a crude white powder, which they recrystallized from acetone-ethanol. The final yield of extracted toxin was 5.6 +/- 0.7 mg per 10^9 cells.

After purifying the toxin, Baden *et al.* (1981) performed a variety of *in vivo* and *in vitro* assays. The *in vivo* assays were fish assays using adult female mosquito fish. Purified T_{34} was 20 times more toxic to the fish than to the other animals tested, which included mice and sea urchins (even though it was still found to be highly toxic to mice; LD_{50} = 0.20 mg/liter). The LD_{50} for the fish was 0.011 mg/liter. For one of the *in vitro* assays, KCl was injected into the body cavities of a group of sea urchins to induce the release of eggs and sperm; T_{34} inhibited the development of the fertilized eggs.

The next major advance came when Baden *et al.* (1984) produced brevetoxin antibodies in a goat. Antibodies are useful to help understand the biosynthetic routes of the toxin in the organism itself or the detoxification pathways it travels in transvectors. Baden *et al.* achieved a sensitivity of 600 pg toxin, several orders of magnitude more sensitive than the mouse bioassay. Nevertheless it takes about 50 MU as a starting point for potential human illness to occur; open beds with less than 20 MU have not made people sick to our knowledge.

Baden *et al.* (1984) chemically reduced T_{34} to T_{17} after purifying T_{34} to crystallinity. They coupled this to bovine serum albumin (BSA), an effective antigenic carrier. T_{34} is a haptenic toxin; because of its small mass (895 daltons; Trainer and Baden 1990) it must be coupled to a carrier molecule to initiate an immune response. For 4 weeks, a single, castrated male mongrel goat was immunized with 0.25 to 0.33 mg T_{17} equivalents of the antigen at weekly intervals. It was immunized once 2 weeks later, and at 21-day intervals after that. The antigen was injected intramuscularly into each hindleg, and the antiserum obtained starting 5 weeks after the initial immunization. Each antiserum was transformed into gamma-globulin fractions. The highest titers of the specific antibody were obtained 1 week after the initial 4-week immunization. One limitation of the antibody is that it does not distinguish between T_{34} and T_{17}, so for now we must accept cross-reactivity of brevetoxins, and even ciguatoxins.

iii. Radioimmunoassay (RIA)

In the same paper, Baden *et al.* (1984) reported using the antibody for a radioimmunoassay (RIA), which his group developed between 1983 and 1985. They reported the development of this quantitative method in much greater detail in a paper published in 1985.

A radioimmunoassay counts the gamma-ray emission of radioactive products produced by specific antibody responses to *G. breve* toxins. It is a competitive assay in which pre-prepared vials contain a brevetoxin antibody and tritium-labeled brevetoxin [H^3-T_{17} hapten, which is the same as tritiated PbTx-3; T_{34}=PbTx-2]. If the added extract does not have brevetoxin, the tritiated brevetoxin binds to all of the available antibodies, and its disintegration per minute (dpm) count will be low. However, if the added extract does contain brevetoxin, competitive binding occurs between the tritiated brevetoxin and the unknown extract based on relative concentrations in the preparation. Centrifugation removes the bound tritiated brevetoxin prior to counting in a scintillation counter (cf. Hurst *et al.* 1985). A standard curve is constructed, and results are expressed as the percentage of labeled toxin bound in the presence of increasing concentrations of cell extract.

RIA results suggest that the amount of toxin present is 9.0 pg/*G. breve* cell (Baden *et al.* 1985). Baden's group also used the assay to detect toxin in tropical marine fish liver extracts. It was quicker and more sensitive, so the method was initially considered superior to the mouse bioassay at first. An inherent disadvantage, however, is that it cross-reacts with all brevetoxins and ciguatoxins, which have similar chemical backbones and overall structures (Baden *et al.* 1995). In a later paper, Baden *et al.* (1988) wrote that it is "definitely an easier, less expensive assay, but may be less representative of the composite potency of the subject food sample. Non-potent compounds such as oxidized PbTx-2 may give a false-positive result, and more potent compounds such as the type-2 toxin series may go undetected. For Public Health use, this potential shortcoming makes the assay unacceptable."

The tritiated PbTx-3 probe has been used to characterize the brevetoxin binding component in rat brain synaptosomes (receptor binding assay discussed after ELISA). Poli *et al.* (1985) were among the first to report these types of studies. Baden *et al.* (1988) compared brevetoxin binding in the synaptosome assay and the RIA. In the RIA, toxin affinity is based on all of the antigenic determinants of the immunizing toxin. In the synaptosome assay, affinity is based on the portion of each toxin molecule that binds to the specific Na+ channel site. The former better reflects the potency of each toxin examined, while the latter reflects structural similarities to the tritiated toxin probe.

Baden *et al.* (1988) noted limitations of both methods. Similar to the RIA, the rat brain assay lacks specificity. It is based on preparations containing the voltage-sensitive Na^+ channels to which brevetoxins bind, but other toxins such as saxitoxin derivatives and ciguatoxin may bind to the same site. The synaptosome preparation is also inherently unstable, so fresh tissue must be prepared daily.

iv. Enzyme-linked immunosorbent assay (ELISA)

The search for an improved assay continued into the 1990's. The next assay developed was the enzyme-linked immunosorbent assay (ELISA) which measures light absorbance changes (visible region) resulting from complexes that form when brevetoxin antibodies react with a peroxidase-linked coenzyme. Trainer and Baden (1990) developed this assay, which was considered superior to the mouse assay and RIA because the latter two were not practical for field applications. The ELISA was more accurate and sensitive, and it could be read visually without expensive equipment.

The ELISA uses 96 microtiter plates that can accommodate a large number of samples. It is a very specific, sensitive assay; many molecules of product can be generated by a single molecule of enzyme. Trainer and Baden (1990) used the anti-brevetoxin antibody raised in goats and linked it to a toxin-HRP (horseradish peroxidase) complex, a relatively inexpensive, efficient conjugate. The assay detects either the brevetoxin antibody or the brevetoxin alone (via a competition assay). Trainer and Baden also used a brevetoxin-urease conjugate, but had difficulty obtaining a stable enzyme preparation. They concluded that while the ELISA was promising, it needed to be improved before it would be used successfully in the field. Another limitation of the ELISA is that it can usually detect only one compound or one class of compounds using the specifically prepared antibody (Hua *et al.* 1995).

v. Receptor binding assays

In in vitro receptor binding assays labeled toxin binds to broken nerve membrane fragments on brain synaptosomes (Steidinger and Baden 1984). The method is advantageous in that the toxin binds to a specific site on the Na+ channel, and the binding measured is the pharmacologically significant event responsible for the onset of poisoning. Therefore, the degree of competition for specific binding sites measures the true potency and the corresponding public health hazard.

vi. HPLC-ESMS

Table 5 summarizes the various methods of brevetoxin analysis discussed by Hua *et al.* (1995). The general problems encountered in the search for the ideal assay included low sensitivity, long analysis time, and lack of specificity. Hua *et al.* (1995) described a new method to remedy these problems: on-line high-performance liquid chromatography-electrospray ionization mass spectrometry (HPLC-ESMS). HPLC-ESMS could separate and identify brevetoxins, and the total analysis only took about 35 min. Of the 9 known brevetoxin derivatives, Hua *et al.* found at least 6, including 2 well-separated peaks corresponding to PbTx-1 and PbTx-2, and 1 possible isomer of PbTx-9. The detection limits for these derivatives were 600 fmol (femto-=10^{-15}), 1 pmol, and 50 fmol, respectively. The results suggested a high tendency for brevetoxin molecules to bind to alkali cations. The main drawback of this method is its relatively expensive cost and the fact that it is performed only in the laboratory. As mentioned earlier, a sensitive and quick field assay is what managers currently need most. Therefore, the search continues.

vii. Evaluation

Methods for brevetoxin analysis were developed in a linear fashion – they improved over a relatively short period of time. Nevertheless, there were many sources of confusion in the literature, especially in the earlier years of brevetoxin research. First, three different types of assay units have been reported: the toxin unit in the fish bioassay (Starr 1958), the mouse unit (McFarren *et al.* 1965), and the hemolytic unit (Martin *et al.* 1972). It is interesting that out of all the methods devised, the mouse bioassay (the first assay developed) is still the only one that is FDA-approved. Furthermore, much of the early data on the toxins is vague and confusing because methods, results, and naming of the toxins differed from laboratory to laboratory (cf. Baden 1983; Shimizu 1978; Alam *et al.* 1975). The small final yield of brevetoxin is another complicating factor (see Baden *et al.* 1981).

D. Blooms

A bloom is defined as a population of *G. breve* cells that is above background levels (Steidinger and Vargo 1988). Blooms are often discolored water masses because of the absorbing and scattering properties of *G. breve* cells. However, calling them red tides is on the brink of a misnomer because blooms of a variety of species have also appeared as mixtures of orange, green, yellow and brown. It is more common to call them harmful algal blooms rather than red tides although the term "red tide" is still widely used.

1. When, Where, and How Long?

Blooms most commonly occur in the late summer or early fall months, but they have occurred in every month of the year. It was first thought that red tides began inshore where they were observed. However, Steidinger's analyses of early U.S. Fish and Wildlife Service cruise data confirmed that blooms originate between 18-74 km (10-40 miles) offshore (Steidinger 1975a). Depending upon the hydrographical regime, the blooms either move inshore or remain offshore (Steidinger and Vargo 1988; Tester and Steidinger 1997). Sometimes red tides extend for thousands of square kilometers (Vargo *et al.* 1987), while other times the patches are relatively small in size. Furthermore, the hot spot for red tide activity is between Clearwater and Sanibel Island on the Florida west coast (Joyce and Roberts 1975) but they have occurred all over the Gulf coast, and sporadically in parts of the Atlantic as well (Murphy *et al.* 1975; Roberts 1979). About 70% of blooms recorded since 1878 lasted between 1-4 months; approximately 15% have lasted between 8-12 months (Table 7, Fig. 1,).

a. Bloom stages

Steidinger and Vargo (1988) described 4 bloom stages: initiation, growth, maintenance and termination. The following discussion is based largely upon their descriptions. It will be shown that the life cycle of *G. breve* is intimately connected with the blooms stages it undergoes, and there is also a strong connection between the physical regimes in the Gulf of Mexico and the various bloom stages.

Table 7. Summary of *G. breve* Blooms – Year, Duration/Intensity, Location.
(H: heavy; M: moderate; L: light); All H, M, or L designations are taken from Feinstein (1956).
Sources of information:
1: Department of Environmental Protection (DEP), St. Petersburg, Florida 33701, **2**: Gabriel Vargo, Ph.D., University of South Florida, St. Petersburg, Florida 33701, **3**: Rounsefell and Nelson 1966, **4**: Steidinger and Ingle 1972, **5**: Gunter et al. 1948, **6**: Davis 1948, **7**: Finucane 1964, **8**: Dragovich and Kelly 1966, **9**: Smith 1975, **10**: Simon and Dauer 1972, **11**: Dauer and Simon 1976, **12**: Murphy and others 1975, **13**: Roberts 1979.

Year	Intensity* and/or Duration (months)	Location (when available)
1844	H	-
1854	M	-
1856	L	-
1865	M	-
1878	H; 3	Tampa to Dry Tortugas [1]
1879	L	-
1880	M-H; 5	Tampa to Key West [1]
1882	L-M; 1	Clearwater to Egmont Key [1]
1883	L; 3	-
1885	L; 1	Egmont Key to Charlotte Harbor [1]
1886	L	-
1908	8?	-
1916	H; 2	Boca Grande to Big Marco Pass [1]
1924	M	-
1925	L-M	-
1931	L	-
1932	M	-
1935		Texas [3]
1936	L-M	-
1946-47	H; 8 or 9	First noted off Naples, but reports stretched from Florida Keys northward to St. Petersburg area [5,6]
1948		South Texas [3]
1949	L	-
1951	L	-
1952	M-H; 5	Near Sanibel Island [1]
1953	M-H; 6	Venice south; Florida Bay / Dry Tortugas [1]
1954	M-H; 12	Highest concentrations from Boca Grande to Cape Romano [7]; Venice and south – inshore between Marco Island and Anclote Keys [1]
1955	2	Questionable in Texas; Two sources said it was not a red tide year [3,7]; Boca Grande [1]
1957	4	Blooms occurred sporadically between Anclote Key, Egmont Key, Venice, and Everglades [7]; Tampa and south [1]
1959	4	Tampa to Venice, offshore and slightly south of Sanibel, north to Anclote Keys [1]
1960	4 [1] or 8 [2]	Venice to just below Cape Romano, south of Sanibel, Egmont Key [1]
1961	4	Possible discoloration, but no recorded outbreak [1]
1962	2	-
1963	1	Inshore Collier County and Tampa Bay [1]

Table 7 (continued)

1964	3	Highest concentrations off Venice Inlet, intermediate levels at John's Pass and Anna Maria Island, low at Boca Grande Pass in the south [8]; offshore Apalachee Bay (first recorded red tide north of Tarpon Springs) [1]
1966	1	Offshore Tampa Bay [1]
1967-68	5	Fort Myers / Marco Island [1]
1970	1	Offshore northeast Gulf of Mexico [1]
1971	3.5 [4] or 4 [1]	St. Petersburg south to Naples, including Tampa Bay [1, 9, 10, 11, 4]
1954	M-H; 12	Highest concentrations from Boca Grande to Cape Romano [7]; Venice and south – inshore between Marco Island and Anclote Keys [1]
1955	2	Questionable in Texas; Two sources said it was not a red tide year [3, 7]; Boca Grande [1]
1957	4	Blooms occurred sporadically between Anclote Key, Egmont Key, Venice, and Everglades [7]; Tampa and south [1]
1959	4	Tampa to Venice, offshore and slightly south of Sanibel, north to Anclote Keys [1]
1960	4 [1] or 8 [2]	Venice to just below Cape Romano, south of Sanibel, Egmont Key [1]
1961	4	Possible discoloration, but no recorded outbreak [1]
1962	2	-
1963	1	Inshore Collier County and Tampa Bay [1]
1964	3	Highest concentrations off Venice Inlet, intermediate levels at John's Pass and Anna Maria Island, low at Boca Grande Pass in the south [8]; offshore Apalachee Bay (first recorded red tide north of Tarpon Springs) [1]
1966	1	Offshore Tampa Bay [1]
1967-68	5	Fort Myers / Marco Island [1]
1970	1	Offshore northeast Gulf of Mexico [1]
1971	3.5 [4] or 4 [1]	St. Petersburg south to Naples, including Tampa Bay [1, 9, 10, 11, 4]
1980	8 [1] or 6 [2]	Near and offshore Tampa Bay, offshore 10,000 Islands / north Keys, near and offshore south of Cedar Key to south of Charlotte Harbor; alongshore Jacksonville to Canaveral [1]
1981	2	Near and offshore Tampa Bay to Charlotte Harbor; along Keys and north of Miami [1]
1982	8 [1] or 5 [2]	Inshore Charlotte Harbor to Naples, Venice to Marco [1]
1983	3 [1] or 5 [2]	Inshore and offshore north of Tampa Bay to Charlotte Harbor, nearshore Cape Canaveral / north of Miami, near and offshore Sanibel to Marco [1]
1984	6 [1] or 3 [2]	Near and offshore north of Tampa Bay to Key West [1]
1985	4 [1] or 3 [2]	Offshore north of Tampa Bay, alongshore Sanibel Island; Tampa Bay to Charlotte Harbor [1]
1986	4	Near and offshore Tampa Bay to Charlotte Harbor [1]
1987	6	Bloom initiated in Sarasota-Charlotte Harbor area; transported to North Carolina continental shelf; near and offshore Tampa Bay and nearshore Charlotte Harbor [1]
1988	2	Near and offshore Tampa Bay to Marco Island [1]
1989	2	Nearshore Tampa Bay to Sarasota [1]
1990	2	North of Tampa Bay to Sarasota and Charlotte Harbor [1]
1991	5	South of Tampa Bay to Charlotte Harbor [1]
1992	4	-
1993	1	-
1994	4	-
1995	12	Off and on throughout north Florida, southwest coast, Keys [1]
1996	10	Primarily offshore central Florida coast [1]
1997	3	Offshore central Florida coast [1]

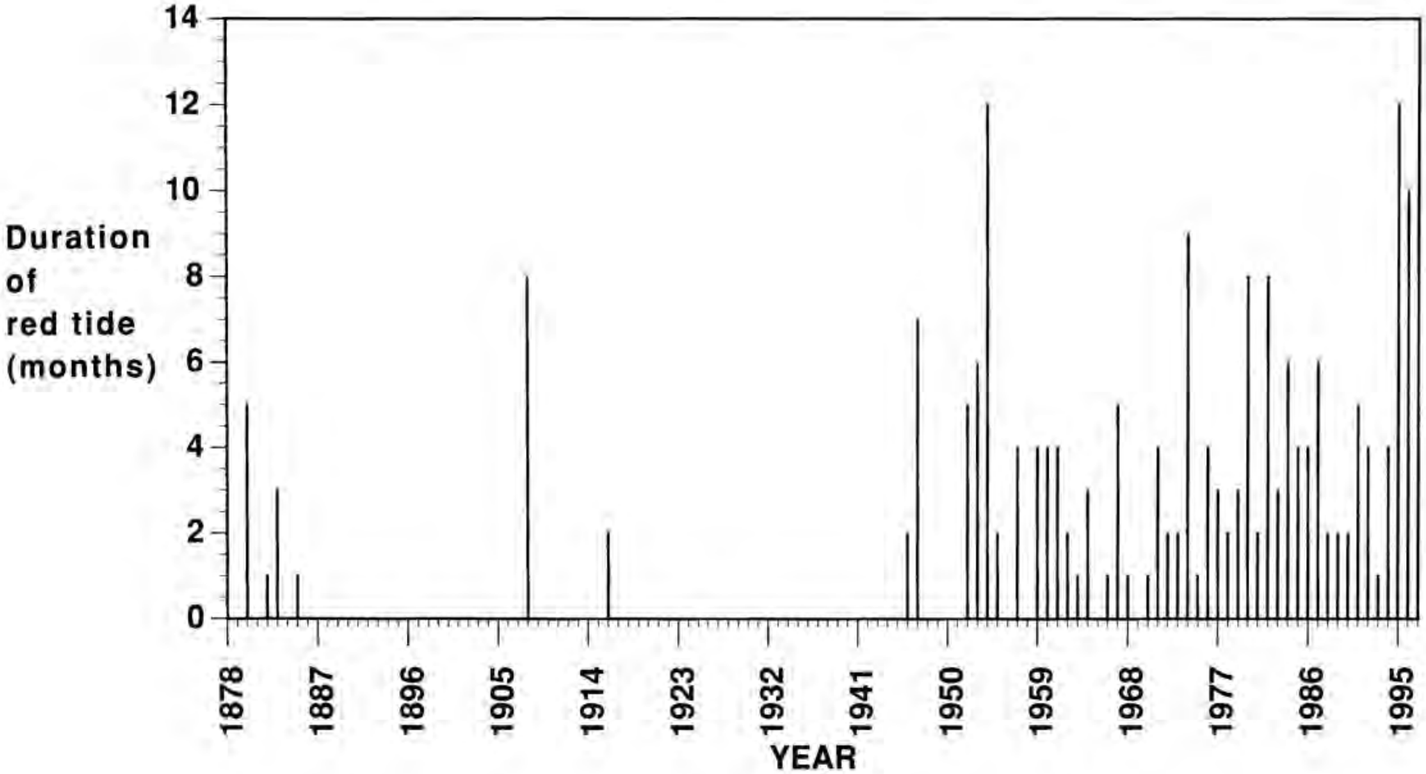

Figure 1. Red tide year verus bloom duration in months.

Many questions regarding bloom initiation continue to vex researchers today. Steidinger (1975 a and b, 1983) and Steidinger and Haddad (1981) expanded upon an idea raised earlier by Prakash (1967) that *G. breve* has a benthic resting stage called a hypnozygote. The hypnozygote, produced from the sexual fusion of gametes when a vegetative planozygote encysts, is a thick-walled cell with reduced organelles and reduced metabolic activity. It could play a significant role in the initiation of *G. breve* blooms along the west Florida shelf when temperature or light changes cause the hypnozygote to excyst, but this has yet to be proven in the field or demonstrated within the laboratory. The patchy or localized distribution of *G. breve* blooms is nevertheless consistent with the idea of seed beds as the source inoculum.

After initiation, a bloom grows if the hydrographic, chemical, and biological conditions are favorable. Blooms may persist for months at high cell levels around 10^4 to 10^6 cells/l (Vargo and Shanley 1985). It has been shown that *G. breve* can use a variety of organic and inorganic nutrients, and it survives over a relatively wide array of temperature and light conditions. It also needs vitamins and chelators to grow in the water column; the water masses in which blooms grow may be preconditioned with nutrients and these other substances by blooms of other species. Furthermore, the toxins produced by *G. breve* may contribute to its near monospecificity in a bloom situation. Finally, its diel migratory behavior (*G. breve* is positively phototactic and negatively geotactic) enables it to migrate through a weak thermal gradient (Heil 1986), thus signifying another growth strategy.

The third bloom stage is the maintenance stage, during which growth must exceed losses by advection, predation and natural death. A stable, stratified water column favors the retention of blooms, conditions that typically exist in the summer and fall months. Blooms are maintained or entrained by a variety of physical regimes including fronts, convection cells, internal waves (seiches), thermal boundaries, or other gradient boundaries.

The final bloom stage is termination. Grazing, cell death, advection, nutrient limitation and dilution of a favorable physical chemical environment can all contribute to the end of a *G. breve* bloom.

b. Evaluation

The role of seed beds as the source inoculum for *G. breve* blooms was first proposed by Steidinger in the early 1970's. The mechanism of how blooms start remains unknown. Seed beds have not been found in the field, nor has the production of cyst stages been observed in the laboratory; in short, nothing has been done to bolster or refute the seed bed hypothesis. Understanding how blooms initiate is a key to the whole process of how blooms work – only when bloom dynamics are better understood will we be able to responsibly address control issues. It seems undeniable, therefore, that more work be done to confirm the *G. breve* life cycle, and to integrate what is learned into an interdisciplinary field work approach. For example, if most cysts that occur in other dinoflagellate bloom species are found in silt or clay geologic environments, where could they occur on the west Florida shelf which is primarily made of carbonates? Could they reside in solution holes where other dinoflagellate cysts are known to accumulate? Or is there a long-lived planozygote stage that lingers in the Gulf and takes advantage of boundary currents or defined water masses to maintain bloom development?

Other problems exist in how bloom data are recorded, and how the temporal and spatial scales of blooms are defined. Blooms can extend for thousands of square kilometers, or they can occur within a relatively small spatial scale. High populations can be found from the surface to about 50 m down in the water column (Geesey and Tester 1993). There is a need to better define what a bloom is in the first place beyond the traditional definition of a population of cells above background level.

2. Climatological Factors

a. Rainfall and freshwater inputs

Various climatological factors have been proposed as key factors affecting blooms. Rounsefell and Nelson (1966) originally suggested that red tides initiated nearshore because that is where the effects of blooms were observed. As previously mentioned, however, blooms originate about 10-40 miles offshore, and they are transported inshore by the dynamic action of winds and tides. In these nearshore areas, however, climatological factors such as rain and river runoff play a role that needs to be evaluated.

Feinstein (1956) tried to correlate red tide outbreaks with various ambient phenomena such as rainfall, tropical disturbances and river runoff. She examined data available from 1844-1954, and found that the most severe outbreaks were preceded by at least 10 years with no recorded outbreak. The data suggested some kind of cyclic pattern, but Feinstein found no linear relationship between the ambient factors and the occurrence of red tides. It should be noted that Feinstein had an incomplete data set; only data from visible blooms that occurred inshore were used (offshore data were not available).

Finucane (1964) recorded the distribution and seasonal occurrence of *G. breve* for a four-year period, and found that the most dense concentrations of cells occurred between fall and winter and were often preceded by periods of high rainfall and land drainage.

About 10 years after Feinstein's work, Rounsefell and Nelson (1966) also attempted to correlate major outbreaks with rainfall and river runoff. Their results were somewhat contradictory but they basically concluded that "high rainfall must be considered as one of the factors favoring outbreaks."

Ingle and Martin (1971) investigated the association of *G. breve* red tide outbreaks with the Peace River drainage of Fe with tannic acid, humic acid and other chelators. They proposed an iron index as a means of predicting blooms, and defined it as the total amount of iron potentially delivered to an outbreak during a three-month period. They tested their idea using riverflow data from 1944-1969 in areas from Charlotte Harbor to Sanibel Island, Florida, where the index was a flux of 235,000 pounds of Fe delivered by the Peace River (assuming optimal temperatures and the absence of extreme weather such as hurricanes). Ingle and Martin postulated that outbreaks start in a small area of Charlotte Harbor and spread outward if there are enough Fe-humic acid complexes in the surrounding areas. Their data suggested that rainfall would lead to an increase in the number of blooms.

A study by Martin *et al.* (1971) is also relevant to this discussion. They analyzed 14 west Florida streams from 1968-1969 and determined the humic acid, Fe, Cu, Mn, and Zn content of surface water samples. (Humic acid is the dark brown macromolecular decomposition product of plant matter; they are significant because they are natural chelators so they can form complexes with metal ions). They also analyzed riverflow data. A general characteristic that emerged from their work was that the northern streams had uniformly lower concentrations of humic acids and soluble metals than the southern streams; the central streams had intermediate values. Many northern streams, however, can still deliver a considerable amount of humic acids and soluble metals because they have a high stream flow. In all rivers tested, a linear correlation existed between humic acid concentration and rainfall and trace metal concentrations. The southern streams showed the most significant correlations and provided more support for the iron index developed by Ingle and Martin (1971). They noted, however, that "the results did not establish that iron or humic acids or a combination is the cause of *G. breve* blooms or even significant to their growth. Some other substance(s) associated with iron and humic acid species may actually be the significant factor."

Steidinger and Ingle (1972) studied the 1971 *G. breve* red tide, which significantly impacted the Tampa Bay estuary. Relevant to this discussion is their suggestion that heavy rains signal a decline in the number of *G. breve* cells because *G. breve* does not do well in low-salinity waters. In a drought, however, salinity is higher than normal, which would support a bloom. The 1971 red tide bloom is a case in point; that year was one reason the bloom persisted so long in the estuarine waters.

b. Evaluation

The information available on how rainfall affects *G. breve* blooms is somewhat contradictory. On one hand, the lower salinity hinders bloom sustenance/formation but on the other hand, increased trace metals and humic substances delivered by rivers after heavy rainfall would seem to stimulate or maintain blooms. It is interesting that many severe blooms have occurred in drought years such as 1946-47, 1971, 1982 and others. More work is needed in this area to clarify the rainfall story and reanalyses of some of the earlier data are in order. It also seems that more long-term studies such as that performed by Feinstein (1956) are necessary to delineate long-term trends in the stages of *G. breve* blooms. The studies should examine nonlinear relationships rather than (or in addition to) the linear relationships sought by Feinstein.

3. Physics

A tight coupling exists between the biology of *G. breve* and the hydrography of its environment. It therefore behooves red tide researchers to have a working knowledge of the Gulf of Mexico's physical regime. Tester and Steidinger (1997) comprehensively documented the role of surface circulation in the initiation, transport, and termination of *G. breve* blooms. Circulation patterns in part dictate the distribution of *G. breve*, which is found largely in the Gulf of Mexico, but has been recorded throughout the U.S. South Atlantic Bight (Tester *et al.* 1993; Tester and Steidinger 1997). It is found in background concentrations of about 1,000 cells/l in the Gulf of Mexico, except in coastal areas off Texas coast and west Florida where local circulation patterns may play a role (Tester and Steidinger 1997; Geesey and Tester 1993; Tester *et al.* 1993).

Following are a few examples of the bio-physical coupling that is fundamental to understanding *G. breve* ecology. First, *G. breve* cells are positively phototactic and negatively geotactic (Heil 1986; Kamykowski *et al.* 1998) so during the day, much of the population remains in the upper water column. Here, cells are subjected to the dynamic action of the winds and currents that transport *G. breve* inshore, where its effects are observed in the form of water discoloration, fish kills, human respiratory irritation, and/or neurotoxic shellfish poisoning. Along the beaches, bubbles in the seawater caused by breaking waves also concentrate brevetoxins at the air-sea interface in the form of toxin-enriched foam, jet drops and aerosol that tend to cause human respiratory irritation (Pierce *et al.* 1989). Second, fronts may act as physical concentrating mechanisms, serving as a barrier to the transport of surface-entrained populations. A third example of the bio-physical coupling is the following. If given the right physico-chemical regime, *G. breve* can express its competitive exclusion strategies to form nearly monospecific blooms, one of its significant biological traits. Finally, blooms dissipate or terminate when the offshore source of inoculum is entrained and/or transported out of the area, or when a confined water mass with *G. breve* is diluted by vertical mixing or horizontal transport (Tester and Steidinger 1997). Again, the physics at work in *G. breve's* environment work synergistically with its inherent biology.

It is necessary to actively approach red tide data in an interdisciplinary fashion. The importance of understanding the Gulf of Mexico dynamics that initiate, maintain and disperse blooms is now indisputable. However, it was not until the 1960's that quantitative measurements were made to better understand the seasonally variable Gulf of Mexico circulation. Following is a sketch of the progression of research that has been done on the physical regime of the Gulf of Mexico, and the ensuing physical-biological connections regarding *G. breve* blooms made along the way. Interestingly, Martyr (1912, cited in Tester and Steidinger 1997) wrote that reports of discolored water and toxin poisonings in tropical Atlantic waters were found in ships' logs by 1530 to 1550, so it seems that some of the first looks at the Gulf of Mexico's physical regime coincided with some of the first observations of discolored water. Although the bio-physical coupling was not clear when these early researchers began exploring the physics at work in the Gulf of Mexico, the physical features would become undeniably significant for red tide researchers in the years to come. The following discussion is broken down into two parts: general physical traits of the Gulf of Mexico (including eddies), and bio-physical coupling characteristics specific to *G. breve*. Each is discussed chronologically.

a. General physical traits of the Gulf of Mexico

The Gulf of Mexico, a semi-enclosed basin, is dominated by three main currents: the Yucatan Current, the clockwise Loop Current, and the eastward flowing Florida Current that rounds the tip of Florida and melds with the Gulf Stream in the Atlantic Ocean. Seasonal variability exists (Weisberg *et al.* 1996). The overall Gulf circulation forms an anticyclonic (clockwise) loop. Early bathymetry charts indicate maximum depths of about 3500 m in the central gulf (Nowlin 1972). A sharp, shallow thermocline typically characterizes the shallow shelf regions, and the bottom water on the shelves is relatively cold (and therefore dense). The Yucatan Current stretches from the Caribbean Sea into the Gulf of Mexico. In the eastern Gulf, water enters through the Yucatan Strait, rotates clockwise through the Gulf, and flows eastward between Cuba and the Florida Keys into the Straits of Florida. The eastern Gulf loop is the primary current feature of surface circulation in the Gulf of Mexico (Leipper 1970); it is a very strong current, and its position is highly variable. It transports more than 25 million m^3/sec of water (1/3 of the Gulf Stream transport) at about 50-200 cm/sec, which is enough to refill the Gulf of Mexico basin in 30 months. In the western Gulf, the circulation is also anticyclonic, but it assumes a NE-SW orientation (Nowlin *et al.* 1967).

Nowlin and McLellan (1967) were among the first to characterize Gulf of Mexico waters in the winter (February and March) of 1963. They observed considerable temporal variability in the current regimes throughout the year. In a later report, Nowlin (1972) reported that winter circulation in the western Gulf is also much more predictable than eastern Gulf circulation. Eastern Gulf Loop water was found to have the highest salinity but in the summer, for example, the salinity is even higher because evaporation exceeds precipitation. Nowlin and McLellan (1967) also reported that at times, the eastern gulf loop water extended as far downstream as the Miami-Bimini region; the northern limit was usually in the southern Florida Straits midway between Cuba and the western Florida Keys. The maximum controlling sill depth was 1650-

1900 m. They also found a secondary oxygen minimum layer at 150-300 m depth throughout the eastern Gulf Loop. In the western Gulf, the oxygen minimum layer was considerably thicker because of a longer residence time.

Leipper (1970) published a frequently cited paper entitled "A Sequence of Current Patterns in the Gulf of Mexico." Similar to the work by Nowlin and McLellan (1967), it described the considerable seasonal variability of the Loop Current. As the Loop Current enters through the Yucatan Straight, it becomes the driving force for the circulation in the entire Gulf of Mexico and is therefore considered the major oceanic feature in the gulf. Leipper participated in eight cruises starting in May 1964 to obtain the physical data. The flow of the Loop Current is mapped out by tracking the 22° C isothermal surfaces; current speed is presumably proportional to the slope of the isothermal surfaces. Leipper found that from July to December, a spring intrusion occurs; the current reaches its maximum flow into the gulf. In the fall months, a general spreading to the western gulf occurs, and is appropriately called the fall spreading. Also, in July and August, the northern end of the loop became a separate eddy of detached flow; however, Leipper considered this an irregular phenomena. The importance of understanding eddy shedding with respect to *G. breve* red tide blooms would not come clear until the late 1970's and 1980's.

Sturges and Evans (1983) documented the variability of the Loop Current to better understand the extent that offshore currents affect flows on the continental shelf. They performed a 13-year-long time series. The variation assumed a broad pattern rather than a sharp peak. They also tracked the position of the 20° C isotherm at 150 m to map out the pattern of the Loop Current (previous studies tracked the 22° C isotherm at about 100 m). The annual fluctuations of the Loop Current appeared to be wind-forced and its north-south fluctuations were related to the coastal sea level and coastal currents. At the outer edge of the west Florida shelf, the current moved between 10-20 m/sec, comparable to the results of Huh *et al.* (1981). Sturges and Evans also documented the roughly annual intrusions that occur, and found that it takes about one and a half months for the Loop Current to form a large meander. They estimated the path length of a large intrusion to be at least 1000 km. Another feature of the circulation that could have a bearing on *G. breve* bloom dynamics is the fact that eddy-like motions occur on the outer edge of the Florida shelf when the part of the Loop Current from the south flows past the outer edge of the continental shelf.

Paluszkiewicz *et al.* (1983) analyzed hydrographic and satellite data (IR data from AVHRR on NOAA-7) from the west Florida shelf between April 1-7, 1982. They described the west Florida shelf region as a transition region; many interactions occur between the off-shelf Loop Current water (36.6-36.8 PSU; 22.5° C in upper 200 m), the continental edge water (colder and fresher), shelf water, and the eddies. They found that the Loop Current generally remains about 45 km from the shelf break. A Loop Current eddy intruded onto the shelf in April; it started as a warm filament of Loop Current water that propagated southward and became separated from the main current by a region of cooler water. The Loop Current intrusion meant that colder, deeper, nutrient-rich water was intruding into the upper slope and outer shelf waters, exchanging heat and salt in the process. The Loop Current induced upwelling of the continental shelf waters. Anticyclonic and cyclonic eddies detach from the Loop Current; the former move north or west whereas the latter impinge on the west Florida shelf. The regions that fall within 200 to 100 m out on the west Florida shelf are affected by these phenomena. The filaments that occasionally detach from the main current by cooler water are of the same order as those that occur in the Gulf Stream; they range from 100-200 km in length, but they are much deeper features (180 m vs. 15-20 m for the Gulf Stream filaments).

Hofmann and Worley (1986) described the major features of eastern Gulf of Mexico circulation by performing a historical re-analysis of hydrographic data obtained in 1962. They described the main clockwise gyre of the Gulf in the upper and intermediate layers (upper 500 m), and the less organized flow in the lower layers. They also noted the region of weak counterclockwise flow that occurs to the north of the Loop Current over the west Florida shelf. Furthermore, Lee and Williams (1988; cf. Tester and Steidinger 1997) reported that the annual cycle of wind stress, northward during the summer and southward in the fall, causes persistent upwelling in the summer and downwelling in the fall over the west Florida shelf. These physical features may also play a role in concentrating or dispersing blooms (Tester and Steidinger 1997).

i. Eddies

Eddy detachment in the gulf was widely speculated (Austin 1955) but not confirmed until the 1960's (cf. Leipper 1970). The literature is unclear about who was the first to officially document an eddy shedding phenomena and early information was qualitative and vague; it assumed a much more quantitative appeal over time. For example, beside the reference Leipper (1970) made to a shed eddy, Leipper *et al.* (1972) described another eddy detachment that occurred in August 1965. The core velocity of the eddy was 113 cm/sec, which is similar to the velocity of the Loop Current at large (about 120 cm/sec).

Nowlin *et al.* (1968) also described what they considered to be the first-ever observed anticyclonic eddy detachment from the Loop Current. They obtained their data from two surveys of the eastern Gulf taken in June 1966 and June 1967, and reported that the upper 1350 m of the eddy transported at least 30 x 10^6 m^3/sec.

In May 1969, Cochrane (1972) reported what *he* considered to be the first description of a detached anticyclonic eddy. Cochrane's research group apparently observed eddies before, but the eddies had never fully detached from the Loop Current. Repeated observations made Cochrane realize that anticyclones usually stray off the main current in the late spring or summer. In general, anticyclonic eddies move westward after they are shed by the Loop Current, but a great deal of variability exists. Cochrane also described a possible mechanism for detachment that involves two meanders: if a meander forms off of the southeastern Florida shelf during the spring or summer, and another meander simultaneously strays from the Campeche Bank area, they grow together and create a cyclonic shear zone that cuts off an anticyclone from the Loop Current. Cochrane also reported in another source (cf. Capurro and Reid 1972) that the Yucatan Current always seemed to be somewhat east of its typical position when an eddy would detach from the Loop Current. Once it detached in May, the eddy did not move that much through the middle of June, but by mid-July, it reached150 km west of its position in May. By mid-September, the Loop Current was still further north and the eddy even further west.

Maul (1977) performed a one-year time-series of the Loop Current using the 22° C isotherm at 100 m depth as the Loop Current indicator and ocean color sensing data (LANDSAT-1). Maul was among the first to recognize that annual Loop Current penetration and detached eddies would become significant factors to consider in understanding *G. breve* blooms (cf. Haddad and Carder 1979). Some eddies that span between 20-50 km, for example, could transport *G. breve* cysts into the euphotic zone and contribute to offshore initiation of a bloom. The eddies also meant large exchanges of heat, salt, and momentum. Maul found Loop Current water on the shelf in September and explained that by September, the initial direction of the Loop Current changed; it assumed an easterly component and flowed directly toward the west Florida shelf. Whereas many researchers believed maximum Loop Current penetration occurred in August and September (minimum in March and April), Maul reported a maximum penetration in July and August (minimum in October and November). Nevertheless he observed considerable yearly variation in the detachment of the anticyclonic eddies.

Paluszkiewicz *et al.* (1983) later reported that both anticyclonic and cyclonic eddies detach from the Loop Current. The former generally move northward or westward whereas the latter often approach the west Florida shelf. These frontal eddies generally consist of a counter-flowing warm filament or streamer of the main current that gets separated by cooler water.

Dietrich and Lin (1994) modeled eddy-shedding, and offered a clearer, more quantitative picture of the phenomena. Eddy-shedding is governed by the Yucatan inflow and Loop Current dynamics. Eddies are salty, warm core anticyclonic rings with diameters between 300-400 km and depths of about 1000 m. Between one and three rings separate each year, and the estimated life span of a ring is one year. The average radius for eastern Gulf rings is about 183 km whereas western rings have a radius of about 133 km (the differences are due to dissipation and dispersion of the ring energy as the ring crosses the Gulf). Occasionally, cold-domed cyclonic eddies are observed on the northern boundary of the Loop Current (cf. Vukovich 1995); their diameter ranges from 80-120 km, and they move southward off the west Florida shelf, approach the Florida Straits, and from a cold meander that either dissipates or moves westward across the Loop Current to form a shed eddy. Shed eddies lose energy as they propagate westward as solitary Rossby waves across the various topographic contours.

ii. Bio-physical coupling characteristics specific to *G. breve*

Chew (1953) was among the first to publish on the association between Gulf physics and red tide blooms. While Chew was unable to make any direct correlations between the physics and biology of *G. breve* blooms, his work offers a glimpse of the earlier attempts to do this. He studied Florida's west coast during a bloom in November 1952. Most of his measurements were chemical or biological (for example, salinity, P), but he inferred physical properties from them. Along with a group from the University of Miami, he monitored 11 hydrographic stations to provide a three-dimensional description of the *G. breve* bloom area off Fort Myers, Florida. The farthest station he studied offshore was 7 or 8 fathoms deep (42-48 ft). Chew recorded differences between the warm, saline Gulf water and the less saline river water; it was thought at this time that riverine influences triggered the blooms. He recorded temperature, salinity, P, and made qualitative assessments of isolated current regimes. He also described seasonal advective mixing processes and eddying motion around the northerly current and its southerly countercurrent, but he did not refer to the currents in any quantitative detail.

The importance of understanding the physics of the Gulf of Mexico in association with *G. breve* blooms was clarified after the red tide that occurred on the east coast of Florida in November 1972 (Murphy *et al.* 1975). Red tide conditions only lasted a month, but it was the first documented *G. breve* bloom on the east coast; all of the previously documented blooms occurred off Florida's west coast in the Gulf of Mexico. This was one of the first studies in which the significant influence of the seasonally variable Loop Current on red tide blooms became evident. Instead of penetrating northward into the Gulf of Mexico, the Loop Current remained entrained near the Florida Keys and the Straits of Florida. Also, the inshore shelf waters north of the Keys that typically flow westward, flowed southward through the Keys. It was hypothesized that these two anomalous current boundaries acted as a concentrating mechanism for *G. breve*, and ultimately transported the bloom synergistically with easterly winds and eddies to Florida's east coast, where fish kills and human respiratory irritation were documented. [Note: Another minor east coast bloom occurred in 1977 (Roberts 1979)]. Most *G. breve* blooms occur in the Gulf of Mexico, but according to Tester *et al.* (1991), four documented occurrences of *G. breve* have been recorded on Florida's Atlantic coast (cf. Murphy *et al.* 1975; Roberts 1979; Steidinger and Haddad

1981). This paper reports a more current estimate of six blooms that have been transported to the east coast (1972, 1977, 1980, 1983, 1987, 1995). These blooms all lasted from several weeks to two months and may be influenced by the Tortugas Gyre (Lee *et al.* 1994).

An article by Balch (1979) dealt with the Gulf Stream on Florida's east coast. It too, highlighted the importance of the connection between physics and biology in terms of understanding phytoplankton dynamics. Balch's work is significant because in 1980, a *G. breve* red tide occurred along the east coast of Florida near Jacksonville; this bloom showed how Gulf Stream meanders have the potential to inoculate inshore areas (cf. Tester and Steidinger 1997). Gulf Stream transport was also an important factor in an unusual *G. breve* red tide that occurred along the North Carolina coast in the fall and winter of 1987 and 1988 (Tester *et al.* 1991; cf. Tester and Steidinger 1997). Balch observed a cyclonic Gulf Stream ring around 33° N latitude which, like the Loop Current eddies, resulted from a meander of the Gulf Stream. He found a high diversity of diatoms on the exterior of these large ocean features; dinoflagellates and blue-greens dominated the interior. (The dinoflagellates are adapted to the low-nutrient environments of these Gulf Stream rings, and the diatoms are more adapted to the upwelled nutrients, higher velocities and turbulence characterizing the bloom exterior.) Balch concluded that when the ring finally coalesces with the Gulf Stream one to two years after detachment, it could provide a major seeding source for areas further south and act as a mechanism for patch formation.

A similar idea was explained in a well-referenced article by Haddad and Carder (1979), who studied the Loop Current, west Florida shelf, and the *G. breve* bloom of 1977. Haddad and Carder suggested upwelling and Loop Current intrusion onto the west Florida shelf as a mechanism that resuspends *G. breve* resting cysts and provides proper conditions for excystment and growth (for example, temperature decreases, increased light availability, increased nutrients). Upwelling on the west Florida shelf could be caused by the southward flow of the Loop Current along the upper slope and outer shelf areas. Haddad and Carder documented Loop Current intrusion to within 20-40 nautical miles off Sarasota, Florida; the Loop Current waters at 80 to 125 m depth were characterized by cooler temperatures (19-23° C) and higher salinity (>36.5 PSU).

Haddad and Carder made the connection between the intrusion of this colder water and the typical initiation region for *G. breve* blooms (18-74 km offshore; Steidinger and Haddad 1981).

Similar to Murphy *et al.* (1975) and Haddad and Carder (1979), Tester *et al.* (1991) noted the tight coupling between the physical dynamics of the Gulf of Mexico and the occurrence of *G. breve* blooms. They offered further support that the Loop-Current-Florida Current-Gulf Stream system can transport *G. breve* cells off the southwest Florida coast, around the tip of Florida, and up the east coast. They described the first record of *G. breve* occurring north of Florida; it bloomed in the nearshore waters off North Carolina, which meant a range extension of more than 800 km. They called it an expatriate bloom because it resulted from unusual hydrographic conditions. The bloom was hypothesized to have originated in the Naples area. The estimated transport from the tip of Florida up to North Carolina was between 22 and 54 days, which coincides with the surface flow of the Gulf Stream. About 19 days of satellite images showed the shoreward movement of a Gulf Stream filament that Tester *et al.* hypothesized to be the source of the *G. breve* cells.

Lee *et al.* (1994) provided another classic example of the importance of coupling physics with biology in the Gulf of Mexico. It usually takes between 8.5 to 12 months to form a gyre in the Gulf. The formation of gyres influences food supply, retention and shoreward transport for recruitment in the Florida Keys of locally spawned snapper and grouper larvae, and possibly local lobster recruitment pathways combining advective influences from the Tortugas gyre, Loop Current, and shelf circulation. They documented cold, cyclonic gyres and large offshore meanders of the Florida Current in the southern Straits of Florida. Again, gyre formation depends upon the orientation of the Loop Current as it enters the Straits. If the current is well developed and overshoots its entry to the southern Florida Straits, a cold recirculation occurs off Dry Tortugas; otherwise, the Yucatan Current turns clockwise into the southern straits and no gyre forms. Furthermore, between gyre periods, there are periods of intense eastward flow (Lee *et al.* 1994) that may affect transport of *G. breve* from the west Florida coast to the Atlantic (Tester and Steidinger 1997).

Finally, according to Tester and Steidinger (1997), some blooms can be maintained within the midshelf zone and continually inoculate the nearshore waters or recur in the red tide hot zone from Clearwater to Sanibel Island, Florida. They found one possible mechanism for this in a physical oceanographic study by Weisberg *et al.* (1996). Seasonal wind reversals (northeast-southwest flow) occur on the midshelf that result in zero mean flows in the along-shore and across-shore directions over a 16-month period. As suggested by Tester and Steidinger (1997), the zero mean flow could be a physical phenomenon that entrains blooms offshore so they continually inoculate the inshore areas. Seasonally variable thermal front systems and integrated water masses could contribute to overall bloom maintenance (cf. Steidinger and Haddad 1981). It is also significant to examine the increased upwelling events that can occur during El Niño years, which could also create distinct water masses capable of supporting *G. breve* blooms.

b. Evaluation

Studying the physical regime of the Gulf of Mexico and the biology of *G. breve* appear to be two separate disciplines but they are far from unrelated. The Gulf of Mexico is a dynamic physical regime (for example, eddies, Loop Current intrusions); *G. breve* has an equally dynamic biology. It is capable of adapting to considerable changes in temperature, nutrients and light. It was only when the interdisciplinary approach were applied, for example, that Haddad and Carder (1981) recognized the importance of Loop Current intrusions in the dynamics of bloom development. Coupled biological-physical research is required if the ecological dynamics of red tide blooms are to be unraveled. Modeling efforts aimed at prediction will not succeed without this interdisciplinary information.

One research area that specifically warrants more discussion is the relationship between the variable Loop Current and the life cycle of *G. breve* (Steidinger *et al.* 1997). Researchers still do not have a clear idea of how blooms start and how they end. As discussed earlier, seed beds have been hypothesized but not yet found and until this can be done, the bio-physical dynamics of red tide blooms remain subject to question. The general point to be made is that it is time for researchers to take a more interdisciplinary approach to the study of red tides.

E. Ecology

Without understanding the fundamental role that *G. breve* blooms play within the dynamic Gulf coast ecosystem, any efforts toward their control need to be closely evaluated and researched (Steidinger and Joyce 1973; Anderson 1997). As stated by Pierce in a recent newsletter, "Red tides represent a natural process, not caused by pollution or disruption of the marine environment. These blooms serve a purpose in the ecology of the Florida Gulf coastal regions. Our responsibility is to understand the purpose and function of red tides, directing our efforts toward alleviating the adverse effects without causing further ecological damage."

Nevertheless local Florida-based citizen groups today like START (Solutions To Avoid Red Tide) continue to push for control measures. One of the most recent publicized efforts was reported in *The St. Petersburg Times* on February 24, 1997. The Associated Press story discussed the push by START to look into using clay as a potential method to control red tides (a method used in Asia to help control their red tides). However, control measures that are not backed by a sound, comprehensive understanding of the species-specific phenomena at hand should be regarded with caution.

The literature on Florida red tides suggests that they may best be treated as natural disasters like hurricanes; red tides are phenomena that have existed throughout Florida history and they are a part of what it means to live in Florida. Dead fish and watery eyes aside, a red tide brings about a natural perturbation event to which the system at large has adapted. However, Florida red tides are frustrating to researchers and the general public because not enough is known about their fundamental ecology. "Just when we think we know what red tide is doing, it throws us a curve," said Richard Pierce, Director of the Center for Eco-Toxicology at the Mote Marine Laboratory in Sarasota (Olinger 1996). If, as suggested, red tides do act as a type of natural disaster, then perhaps efforts should be refocused on mitigation measures rather than control measures. Just like it is not possible to control hurricane activity, it may not be feasible or desirable to control red tides. Nevertheless, we should not be so influenced by our own paradigms to exclude either discussions or well designed, small-scale research on control.

Current research efforts dealing with Florida red tides are keeping this ecological focus in mind. An example is the ECOHAB: Florida program (http://www.fmri.usf.edu/ecohab) effort that has recently been funded. One of its primary goals is to elucidate information about the basic ecology of *G. breve* so that models can be formulated that would ultimately predict bloom formation and help in mitigation efforts.

1. Role in Food Web Dynamics

Marine food webs tend to be longer than terrestrial food webs, and as a natural part of the ecosystem, red tides certainly have a niche within the web (Anderson and White 1992). Phytoplankton in general are known as "the grass of the sea" and play a significant role in the conservation of solar energy to chemical energy (photosynthesis). As planktonic dinoflagellates that are always present in the Gulf of Mexico, the *G. breve* population constitutes a fraction of the base of the food web. *Gymnodinium breve* is just one of about 65 toxic dinoflagellate species out of a total of about 2,000. The regularity and seemingly increasing frequency at which outbreaks occur, however, make them a potentially significant part of the system at large (Hallegraeff 1995).

The toxins produced by *G. breve* can affect a wide variety of animals (Anderson *et al.* 1993). Intermediate vectors of the toxin transfer it to higher trophic levels and among those affected are filter-feeding bivalve molluscs, zooplankton, fish, crustaceans, sea birds and marine mammals. However, much of this type of information is qualitative at best. For example, the types of biochemical reactions that occur in planktivorous fish that have pumped brevetoxin-laden water through their gills are understood, but quantitative models specifically depicting what happens to the toxins as they move up the food web do not yet exist (Anderson *et al.* 1993). Toxin chemistry may also be altered as it is metabolized by various animals (Baden, pers. comm.), but studies on biotransformation have thus far been limited.

Another interesting subject dealing with the role of *G. breve* blooms in food web dynamics is its association with diatom or other algal blooms. For example, *G. breve* often co-occurs with *G. mikimotoi* (Steidinger *et al.* 1997). The role of *Trichodesmium erythraeum* blooms in association with *G. breve* blooms has also been questioned since the 1950's (cf. Chew 1953). *Trichodesmium* is a filamentous, N-fixing cyanobacterium, and it has been established that *Trichodesmium* blooms occur prior to most, if not all *G. breve* blooms (Steidinger and Baden 1984) – perhaps *G. breve* is stimulated by the resultant organics, chelators and trace metals (Walsh and Steidinger, submitted). These associations warrant more research.

A question that has vexed researchers for years is the following: How and when does a particular algal species like *G. breve* outcompete other algal species to form a nearly monospecific bloom? Does competition occur at all, given the dynamic nature of the natural environment? For example, in a bloom in 1976, *G. breve*, *Cochlodinium pirum* and *G. splendens* were found; the latter two have growth rates that are nearly twice that of *G. breve* but *G. breve* still became the numerically dominant species. Freeberg *et al.* (1979) were among the first to report a study dealing with competition in a *G. breve* bloom situation. It was well known that brevetoxins can kill fish and other marine animals, but what effect did they have on other algal species? Freeberg *et al.* used medium that was preconditioned with lysed *G. breve* cells to ensure the toxins were present, and found that the growth of 18 of 28 tested phytoplankter species (diatoms, flagellates and dinoflagellates) were inhibited when placed in the medium. Interestingly, *G. breve* also inhibited itself. The mean decrease in growth was 71 +/- 24%, and the sensitivity was species-specific. This demonstrated that brevetoxins are algal inhibitors in addition to animal inhibitors (that is, they kill fish). More studies like this clearly need to be done, especially given the fact that *G. breve* demonstrated autoinhibitory behavior, but they take a step in the right direction as far as determining which species, if any, could be used to outcompete *G. breve.* At the same time, however, laboratory-based allelopathic experiments must be treated cautiously, especially when extrapolating results to the real world.

A general conclusion emerges from this discussion: more studies need to be done to determine the nature of the coexistence and the dynamics between the algal species and its potential competitors or predators.

2. Blooms as Boons

A limited number of studies have been published regarding the fundamental ecology of *G. breve*. Vargo *et al.* (1987) were among the first to publish information on the positive side of *G. breve* blooms in terms of their contribution to the west Florida shelf ecosystem ecology. The study results implied that *G. breve* may act as a significant source of carbon for the west Florida shelf food web.

Using field and laboratory measurements, published values, and a CZCS (Coastal Zone Color Scanner) image from 1982, Vargo *et al.* estimated the production rates of *G. breve* blooms on the west Florida shelf. They concluded that *G. breve* blooms can make significant contributions to the annual production on the shelf. Assuming that a bloom lasts for one month, which is a very conservative estimate, and ranges from 5.2-12.4 x 10^3 km^2, total production was estimated to be 2.9-7.1 x 10^5 t C $month^{-1}$, which is considerably higher than non-bloom periods. These estimates challenged the west Florida shelf carbon budgets; they suggested that primary production in the water column was at least five times higher than originally thought.

Steidinger (1983) was among the first to propose that red tides are the ecological equivalent of terrestrial forest fires. The analogy is not a new concept but it has always been left as a suggestion; no work has been done to quantitatively support or refute it. The general idea is that red tides are a natural, recurring perturbation to which the dynamic Gulf coast ecosystem is adapted. For example, Steidinger (1983) writes, "Patch reef communities in the eastern Gulf of Mexico do adapt to fluctuations such as red tides, storms and hurricanes, cold water intrusions, and other extremes or they wouldn't exist."

The analogy would benefit from elaboration. According to Odum (1971), periodic forest fires present a tremendous value to their surrounding environment, especially in the forest and grassland regions of temperate zones, and in the tropical areas that have dry seasons. Light surface fires aid bacteria in breaking down certain plants and in making minerals more easily available for new plant growth. These forest fires are natural phenomena that ultimately jump-start primary productivity and species diversity within their respective ecosystems. Theory holds that they act as a type of natural catastrophe or pulse stability mechanism that perturbs the surrounding environment in an ecologically beneficial way. They control disease, remove unfit species, provide more niches for a variety of animals, and allow pioneer species to invade the area as part of the ecosystem's natural succession (Kozlowski 1974). The fire climax systems that characterize these areas, however, are adapted to the periodic pulses and are considered to be inherently stable systems at large. Do red tides act in a similar way by periodically clearing out parts of the Gulf coast ecosystem in a way that is ultimately beneficial? This theory seems plausible but it has only been discussed as a *possibility*; no research has been done that definitively supports or refutes it. How valid *is* this postulate? How can it be explored further?

One approach to quantitatively validating this theory is to examine defaunation data following red tide events. How do areas that have experienced a red tide bloom react? Few data sets exist to help answer this question. Two main sets that are available were compiled after the 1971 red tide, which only lasted a few months but ranked high on the severity scale. The first is Smith's data (1975), which showed that the coral patch reef systems off of Sarasota, Florida were almost completely defaunated during the outbreak. Recruitment of many fishes and invertebrates, however, occurred within one to two years. Smith suggested that certain red tides may be underestimated in their potential role as regulators of the composition, abundance, and distribution of certain shallow-water reef biotas.

Smith (1979) performed another study in which he applied Macarthur and Wilson's species equilibrium model to his observations of how two isolated patch reefs off of Sarasota, Florida recovered after the 1971 red tide. His general premise was that red tides dramatically affect the ecological stability of patch communities in the eastern Gulf of Mexico because of the sporadic mortalities they incur. This type of dramatic defaunation occurred at least 20 times between 1854-1974 (Steidinger and Joyce 1973), and as suggested by Steidinger and Ingle (1972), minor blooms are probably an annual event in the coastal waters of the Gulf of Mexico. Based upon his data, Smith concluded that the patch reef communities probably never fully climax; community development stops at a sub-climax level when a red tide occurs. He also concluded that while certain similarities were found between the Macarthur and Wilson model and the patch reef recolonization (for example, shape of colonization curves), the reef communities developed in a more predictable succession rather than the random Macarthur-Wilson developments. The reefs developed a compositionally stable community that was nearly identical with the one that existed before the red tide.

The second major defaunation data set was compiled by Dauer and Simon (1976), who worked on marine polychaetes from a sandy, intertidal habitat in upper Old Tampa Bay that were essentially wiped out from the 1971 red tide outbreak. They found that the population re-established within about two years, and similar to Smith's reef community findings(1979), that the species composition was similar to the composition before the red tide event.

3. Role of Bacteria

The role of bacteria in *G. breve* blooms has been questioned throughout the history of red tide research. *G. breve* does not grow axenically – it has been known to survive for two years in cultures without nutrient additions if bacteria are present. However, while bits and pieces of information have been unraveled, a complete understanding is far from a reality. A relatively recent dedicated interest in marine microbiology in tandem with improvements in molecular biological techniques may lead to some answers.

Bein (1954), part of a University of Miami research group, was among the first to actively question of the bacterial role in red tide blooms. However, Bein isolated bacteria from a coffee-colored red tide in 1951 in the Indian River at Melbourne, Florida; it was a bloom he speculated was caused by an armored *Peridinium* species, not *G. breve*. The definitive part of his study dealt with a newly described chromogenic bacterial species he called *Flavobacterium piscicida*. The primary significance of his study is that it demonstrated that there is indeed a bacterial connection in certain red tide blooms. The bacterial species was a non-spore forming, gram negative, straight rod, motile, heterotroph with a pronounced protein requirement that was found singly or in chains.

It killed most of the fish that Bein introduced into his experiment tanks (*Lutjanus apodus*, schoolmaster; *Eucinostomus pseudogula*, sand perch; *Fundulus similis*, killifish; *Mollienesia latipinna*, mollie); death times varied between 5 min and 24 h. Because autoclaved bacteria had no effect on the fish, Bein concluded that *F. piscicida* has a thermolabile exotoxin.

Bein (1954) also observed a *G. breve* red tide in October and November of 1952 along the Florida west coast. He isolated a large unidentified bacterial species and a chromogenic bacterium from bloom samples and hypothesized a connection between the bacteria and the bloom. At the time of his study, however, it was not possible to study pure cultures of *G. breve* so his hypothesis was left more or less untested. In his conclusion, he wrote: "It seems desirable to investigate for the presence of chromogenic bacteria during outbreaks of Red Tide to determine if such bacteria are always present during blooms of *Gymnodinium brevis*. Quantitative studies should also be made." Therefore, although Bein's study is considered among the first to investigate the role of bacteria in *G. breve* blooms, it did not offer any concrete evidence of the connection. Other bacteria studies that assess bacteria as pathogens and bacteria as recyclers are in progress (Ducette et al, in prep.).

Other researchers have taken a closer look at the role of bacteria in the growth of *G. breve* in the laboratory. Ray and Wilson (1957) were the first to report the growth of unialgal laboratory cultures of *G. breve* (Note: no one had bacteria-free cultures). More than anything, however, their results were more of a testament to the toxicity of *G. breve* rather than unraveling more new information about the role of bacteria in *G. breve* blooms. To establish axenicity, Ray and Wilson inoculated routine sterility-test media with samples drawn from the culture vessels just before these materials were dispensed into the experimental containers. (Note: Routine antibiotic treatments to *G. breve* cultures kill the bacteria, but also have a detrimental effect on the *G. breve* cells). In Ray and Wilson's study, death times varied from 4 min to more than 2.5 h depending upon the fish species (*Membras vagrans* died in 4 min; *Cyprinodon variegatus* died in about 2.5 h). They performed another series of experiments with bacteria-free cultures that determined that *G. breve* itself was responsible for killing the various fish species tested; in contrast to Bein's hypothesis, it was not the bacteria killing the fish.

Ray and Wilson put Bein's hypothesis through even more rigorous testing. They performed toxicity tests with pure cultures of *Flavobacterium piscicida* Bein. *Mugil cephalus* (striped mullet) was the test species; in contrast to Bein's results, the fish did not die when exposed to the bacterium. Ray and Wilson also performed experiments with some of the bacteria isolated from unialgal *G. breve* cultures. Results from this segment of their research suggested that 2 main types of bacterial colonies exist in association with *G. breve*; only one type is pigmented, and neither causes fish kills. On the other hand, some type of red bacterium isolated from *G. breve* waters off the west Florida coast did seem to be toxic to fish, but Ray and Wilson stressed the need for further study. This bacterium was never found in an abundance great enough to warrant it as a fish-killing agent. The general conclusion, therefore, was that there was no definite association between chromogenic bacteria and *G. breve* fish kills.

Evans (1973) reincarnated the idea of an association between bacteria and *G. breve* blooms almost 20 years after Bein's initial hypothesis. Evans emphasized that his idea, too, was merely a working hypothesis. He hypothesized that the growth of *G. breve* during a bloom is stimulated by the prior or concurrent growth of marine bacteria which supply vitamins and other growth factors to meet the physiological requirements of the *G. breve* cells. This idea has been amply shown in various laboratory experiments; as mentioned in the beginning of this section, most *G. breve* cultures are not grown axenically for any length of time (Baden 1983).

Evan's hypothesis took shape after the 1971 bloom at Siesta Key near Sarasota, Florida, from which he isolated chromogenic bacteria (motile gram negative rods) from 8 of 10 water samples. After a different minor bloom in September and October of 1972, Evans took more *G. breve* water samples and quantified the associated bacterial populations by preparing serial dilutions in sterile seawater. Each 10-fold dilution (0.1 ml) was evenly distributed on nutrient agar plates. He incubated the cultures for 48 h at 25° C before counting the colonies. This time, none of the initial bacterial colonies were red, but after a few days of growth, some red bacteria did show up. Over time, the growth of *G. breve* declined while the bacterial growth climbed. No bacteria were isolated beyond the third week of incubation. Evans noted many types of bacteria; all were gram negative, but some were rods and others were coccobacilli depending on the age of the culture and medium used.

Evans suggested 2 possible roles for bacteria in *G. breve* blooms: 1) Passive role: cause the discoloration, but the bacteria may be saprophytic and depend on *G. breve* to fulfill part of its proteinaceous nutritional requirements, and 2) Active role: those bacterial species that are not chromogenic may supply vitamins (biotin, thiamine, B_{12}) or other growth factors. In the latter case, Evans hypothesized that nutrients from sources such as upwelling, fish kills, and runoff could stimulate growth of the bacteria in the first place, and that toxins from either type of bacteria could act synergistically with the *G. breve* toxins to kill fish. He said this is most likely a self-duplicating or repetitive process.

4. Control

Harmful algal blooms are a serious and increasing problem in marine waters, yet scientists and funding agencies have been slow to investigate possible control strategies. Research efforts on mitigation strategies such as shellfish-monitoring and aquaculture site management are critically important, but these efforts treat the symptoms without attacking the problem. Government officials and the public want to know what is being done, or what can be done, in terms of direct intervention. So far, there is little to offer other than tentative predictions of bloom reductions decades from now if nutrient loadings are reduced (Anderson 1997).

To responsibly address the question of control, scientists must learn much more about the fundamental ecology of *G. breve*. Some controls have been experimented with, and ideas have been proposed. For example, Baldridge (1975) tried to use water temperature changes as a predictive tool for blooms, and Ingle and Martin (1971) tried to formulate the iron index to correlate river drainage with the formation of blooms. Neither of these methods have proven realistic or fruitful, but various other chemical and biological controls have been proposed. These efforts in controlling red tide blooms have generated intense scientific and public debate (Martin *et al.* 1988). Boesch *et al.* (1997) recently addressed the prevention, mitigation and control of harmful algal blooms. The types of controls will be discussed in the ensuing section.

a. Chemical control

Various chemical controls have been tested on *G. breve* but none have been sufficient or acceptable. Perhaps the most well known chemical effort to terminate red tide blooms occurred in 1957 when copper sulfate ($CuSO_4$) was sprayed from crop-duster planes over 16 square miles of Florida's coast and dragged in bags behind boats (Rounsefell and Evans 1958; Steidinger 1983). This well-known algicide was proposed as a control agent because federal researchers performed an experiment in front of management agencies and the public – when they dropped copper pennies into an aquarium with *G. breve*, it died (Steidinger 1983). However, the effect of the spraying only lasted about two weeks; then the bloom returned. In addition, the $CuSO_4$ proved toxic to many other forms of marine life so scientists abandoned the thought of using it because it was detrimental to the ecosystem at large.

The U.S. Department of Interior had also sponsored research to find "an inexpensive, readily available, and partially selective chemical that would kill cultured *G. breve* in 24 h at 0.01 parts per million." (Steidinger and Joyce 1973). More than 4,500 chemicals were screened (Marvin 1964). However, only about 8 chemicals were deemed acceptable, and these were either too expensive, too difficult to realistically obtain in sufficient amounts, or too inconsistent as far as results in the laboratory went.

Using chemical controls for blooms is fraught with inherent difficulties (Steidinger and Joyce 1973). Lethal *G. breve* concentrations are not always signaled by discolored water so it might be difficult to detect them before their effects are observed in the first place. Blooms have also been known to cover areas as expansive as 14,000 mi^2, and *G. breve* has been found down to about 38 m (Steidinger and Joyce 1973), or even down to 50 m (Steidinger *et al.* 1997). The amount of chemicals needed to terminate them would therefore be enormous. Furthermore, the *G. breve* toxin is only released when the cell ruptures so even if a chemical is found that kills the cell, its toxic effects could still cause fish kills.

b. Biological control

Biological control involves seeding an area with either: 1) a dinoflagellate that would compete for space/nutrients, 2) a pathogen such as a virus that would attack *G.*

breve cells, or 3) a predator that would eat the red tide organism (Steidinger and Joyce 1973). Little data exists to evaluate the three types of biological controls, and each has many potential risks associated with it.

For a time, many suggested using what they thought was a blue-green alga called *Gomphosphaeria aponina* as a control agent (Steidinger 1983). It was tested extensively in the mid- to late-1970's. The organism has a surfactant called aponin that caused *G. breve* cells to rupture. However, this idea was abandoned for many reasons (Steidinger 1983), and recent evidence suggests that *G. aponina* was actually a *Nannochloris* species (Martin and Taft 1998).

The second type of biological control – using a pathogen such as a virus to control blooms – is also highly subjective. Although virus-like particles (VLPs) have been directly implicated in the termination of certain phytoplankton blooms (Bratbak *et al.* 1993; Nagasaki *et al.* 1994), they have not yet been directly associated with *G. breve* blooms. They theoretically appear to be an attractive control agent (Boesch *et al.* 1997) because they replicate rapidly when the host is disrupted and tend to be host-specific. Furthermore, bacteria have implicated in the end of *G. mikimotoi* blooms (Boesch *et al.* 1997), a species with which *G. breve* has been known to occur. As discussed earlier, the association with bacteria is another that warrants more investigation.

The third biological control, finding a predator to kill the red tide organism in massive amounts, seems unlikely because of the observed toxic effects on a wide spectrum of marine animals including fish, invertebrates and mammals. Even if a naturally existing predator were found, it would take a phenomenal number of animals to terminate an average red tide bloom (Steidinger and Joyce 1973). One proposal for this kind of effort was offered by Martin *et al.* (1973). The main problem would be isolating suitable predator organisms but they suggested using a ciliate isolated from one of the red tides they studied. However, there were many logistical limitations that Martin's group recognized, including the volume of water that red tide blooms involve and the number of predators it would take to effectively control a bloom.

c. Other

Flocculents, materials that scavenge particles as they fall to the seafloor after being added to the water, have also been proposed as potential and relatively benign control agents. Clay seems to be the most popular. Clays adsorb algae and eventually fall to the bottom sediments; this strategy of controlling red tides has been used successfully in certain Asian countries (Anderson 1997; Boesch *et al.* 1997). However, much more research needs to be done in this area before trying it on *G. breve* blooms. How effective would it be? What physical and toxic effects could the clays have on bottom-dwelling organisms? Would it create too many anoxic areas on the seafloor? Numerous questions remain as to the long-term effects of flocculents, particularly with neurotoxic species (Boesch *et al.* 1997).

The possibility of surfactants as chemical controls was another possibility. Studies by Kutt and Martin (1974) and Hitchcock (1976) were discussed earlier. Some basic concerns regarding the use of surfactants to control red tide blooms are the following: localized kills of marine organisms other than *G. breve*, some organisms grow better with small surfactant concentrations so blooms of other potentially troublesome organisms might result, and the long-term effects of surfactants are unknown.

d. Ecological control

As discussed earlier, Steidinger (1983) was among the first to propose that red tides are the ecological equivalent of terrestrial forest fires. The general idea is that red tides are a natural, recurring perturbation to which the dynamic Gulf coast ecosystem is adapted. Certain Gulf coast communities, such as the patch reef communities, do adapt to fluctuations such as red tides (Smith 1975). Furthermore, periodic forest fires present a tremendous value to their surrounding environment (Odum 1971); light surface fires aid bacteria in breaking down certain plants, and in making minerals more easily available for new plant growth. In this way, they ultimately jump-start primary productivity and species diversity. They also control disease, remove unfit species, provide more niches for a variety of animals, and allow pioneer species to invade the area as part of the ecosystem's natural succession (Kozlowski 1974). Theory holds that these fire climaxes act as a type of natural catastrophe or pulse stability mechanism that perturbs the surrounding environment in an ecologically beneficial way.

If red tides act in a similar way by periodically clearing out parts of the Gulf coast ecosystem in a way that is ultimately beneficial, could they be ecologically controlled like forest fires? Forest fires can be started and allowed to burn under controlled conditions. If accurate models of *G. breve* are formulated, this type of ecological control might someday be feasible.

5. Chaos Theory, Fractals, and Red Tides

a. Background/hypothesis

Chaos theory developed in the 1960's and 1970's but the theory at large did not gain popularity until the late 1980's (Gleick 1987). Chaos theory has been applied most often to dynamic physical systems like fluid turbulence and the weather, but it has also been applied to everything from predicting stock market fluctuations to describing the geometry of nature and understanding predator-prey interactions. What follows is a general presentation of chaos theory, and how it might be used in the study of red tides to shed light on the dynamics of red tides at large.

The use of chaos theory in *ecological* studies is a relatively new, but promising technique (Hastings 1993). As a branch of nonlinear dynamics (Peat 1991), chaos theory offers a new way of looking at complex systems. It allows for infinite detail and is therefore often thought of as closer to the truth of what natural systems are all about (Peat 1991). The general theoretical premise is that order exists in systems that may first appear disordered. Chaotic systems lie at the mercy of abrupt or catastrophic changes and random motions; a sensitivity exists in these systems that ultimately proves efforts to control them futile. This extreme sensitivity to initial conditions is one of the hallmarks of chaos theory (Gleick 1987; Peat 1991; Hastings 1993; Peitgen *et al.* 1992); it means chaotic systems are predictable only on short time scales. Their long-term prediction is impossible (Hastings 1993).

One of the cornerstones of chaos theory is the concept of fractals. A mathematician named Benoit Mandelbrot (1983) coined the term in 1975 (Hastings and

Sugihara 1993). Fractals, self-similar structures or fractionally dimensioned objects (Peat 1991), are often used to describe the geometry of nature. They have been called "crinkly objects that defy conventional measures, such as length and area, and are most often characterized by their fractional dimension" (Theiler 1990). The fractal dimension is a measure of the roughness of the features. The Earth's topography, for example, is a composite of many competing influences such as faulting, folding, flexing, erosion, sedimentation, and the action of organisms. Fractal dimension is a way of defining the rough features molded by the interplay of various physical and biological influences.

In the words of Hastings and Sugihara (1993), "Natural patterns, especially those in ecosystems, frequently appear irregular, complex, and hard to measure, even at very small scales." Mandelbrot (1983) was the first to show that many (if not most) living components of nature are fractal. As such, they exhibit infinite complexity. Fractal geometry differs significantly from typical Euclidean geometry in which lines, for example, have the dimension of one, squares two, and cubes three. Instead, fractal objects have fractional dimensions *between* one and two or *between* two and three.

Fractals have been used in a variety of ways to better understand natural dynamic systems. A classic, well-referenced example of a natural system with a fractal geometry is the coastline of Britain. Basically, the length of the coast is dependent upon the scale used to measure it. Using a coarse scale results in a shorter length than making the measurements with a finer-tuned scale. Another example is Lovejoy's (1982) application of fractals to the geometry of cloud formations. By examining the area-perimeter relationship of clouds using satellite- and radar-determined areas between 1 and 1.2×10^6 km^2, he showed that clouds have the fractal dimension (D) of 1.35. The area-perimeter relation characterizes the complexity of the perimeter. Using the following equation

$$P \approx \sqrt{\ } A^D \qquad \text{(Eq. 1)}$$

Lovejoy showed that the shapes of clouds are fractal. This means that clouds do not have a characteristic length. Demonstrating a fractal relationship or pattern gives insight into the nonlinear dynamics of the system at large. In a similar study, Krummel *et al.* (1987) determined the fractal dimension of boundaries in deciduous forests using areal photographs and the area-perimeter exponent.

Principles of chaos theory are particularly relevant to understanding various other earth processes as well. For example, in *Fractals and Chaos in Geology and Geophysics,* Turcotte (1992) discusses applications for earth processes such as earthquakes and other natural disasters, erosion, and mantle convections. Furthermore, "the dynamics behind the formation of islands, coastlines, and mountain ranges occurs on many scales. Species, community, and system dynamics in ecosystems represent successively higher aggregates of species-level dynamics" (Hastings and Sugihara 1993). Fractals have also been used to better understand the structure and dynamics of reefs (Hastings and Sugihara 1993), marine sediments (Carmichael *et al.* 1996), floods (Malamud *et al.* 1996), the dynamics underlying complex vegetation patterns and the boundaries of patches (Hastings and Sugihara 1993)

The study of chaos theory and fractals has also recently been applied to studies on forest fires (Malamud *et al.* 1996, unpubl.; Paczuski 1993). (Recall Steidinger's [1983] hypothesis that red tides are the marine ecological equivalent of forest fires.) Hastings and Sugihara (1993) explain that fractals have been used to better understand the functional role of ecological disturbances such as forest fires; for example, their fractal nature and ensuing dynamics help researchers answer the question of whether forest fires should be extinguished in a given region.

It has recently been suggested that forest fires are an example of self-organized criticality (Malamud *et al.* 1996), another trait associated with fractals. Bak, Tang, and Weisenfeld first proposed the concept of self-organized criticality in 1987. The general idea is that large interactive systems naturally evolve toward a critical state in which a minor event can lead to a catastrophe change (Bak and Chen 1991). "A system is in a state of self-organized criticality if when perturbed it returns to a state of marginal stability. The systems oscillates about the point of marginal stability" (Malamud *et al.* 1996, unpubl.). Malamud *et al.* (1996, unpubl.) used power law (fractal) clustering statistics to show that forest fires exhibit self-organized critical behavior. In particular, they showed that the frequency-size statistics of actual forest fires obey power-law statistics to a good approximation. This relationship was surprising because the size of natural fires depends on many different factors including the availability of combustible material, the weather, the wind, and efforts to extinguish the fire. This relationship will become important in the discussion on fractals and red tides.

Fractals also exhibit self-similarity or scale-invariance. This means that observing an object at smaller scales reveals the same geometric pattern as the pattern viewed on a larger scale. Fractals contain structures within structures as in a Chinese box or a Russian doll (Theiler 1990). Two classic examples are the structures of a tree or lung; the limbs or bronchi branch into smaller and smaller segments that are smaller versions of the tree or lung at large. Perfect symmetrical replications of the large object are called regular fractals whereas weaker versions of self-similarity are random fractals. Most natural objects are random fractals (Hastings and Sugihara 1993). If a natural pattern is scale-invariant, it remains statistically unchanged under magnification or contraction over a fairly wide range of scales (Hastings and Sugihara 1993).

b. What are the possibilities?

How can researchers use the principles of chaos theory to better understand Florida red tides? Similar to forest fires, the size and duration of red tides depend upon numerous factors (currents, wind, fronts, stage of life cycle, temperature, salinity, nutrient availability). Also, as stated earlier, fractals have been used to study the boundaries of patches to shed light on the dynamics of the system at large (Hastings and Sugihara 1993). Can fractal principles be used to study red tide patches? Is it possible that red tides obey frequency-size power-law statistics like fires do? Could some physical factor (wind and upwelling) be isolated and correlated to the occurrence and duration of red tides? Questions like these abound. In order to begin finding answers for these questions, a perimeter vs. area analysis could be done to determine if red tide exhibit a fractal geometry.

Furthermore, isn't a bloom situation an example of a self-organized critical phenomena? Is the dynamic Gulf coast ecosystem one that is occasionally perturbed and oscillates about a point of marginal stability? What causes the *G. breve* populations to appear in such high numbers when its growth rate is relatively slow? The pattern seems reminiscent of systems that exhibit critical behavior or abrupt changes. Furthermore, Bak *et al.* (1988) contend that ecological systems are organized such that the different species support each other in a way that cannot be understood by studying the individual constituents separately. This is a well known basic ecological concept. In a relatively small system, species interdependence or tight coupling makes the system at large vulnerable to minor changes. It becomes significant, therefore, to address the size of the system discussed. How big or small is the system of a red tide? How should the red tide system be defined? To what extent can the principles of chaos theory and fractals apply to red tides? What are the potential applications?

Preliminary observations suggest that while red tides typically occur in the late summer and fall months, they have been recorded in every month of the year. Most red tides recorded since 1878 (about 70%) lasted between 1-4 months but approximately 15% have lasted between 8-12 months. Depending upon the hydrographical regime, the blooms either move inshore or remain offshore (Steidinger and Vargo 1988; Tester and Steidinger 1997). Sometimes red tides extends for tens or hundreds of kilometers, while other times the patches are relatively small in size. In short, irregular patterns such as these preliminarily suggest that red tides may behave according to nonlinear, chaotic dynamics. The possibility exists that viewing red tides through this new lens could reveal much about their ecological role and dynamics at work within the Gulf coast ecosystem.

c. Evaluation

It seems that "efforts to find a 'magic chemical bullet' that will somehow kill only a specific, targeted HAB species may be futile, as it is difficult to imagine a unique physiological target or chemical that is characteristic only of one phytoplankton species" (Boesch *et al.* 1997). Nevertheless, the research must continue along with monitoring and mitigation efforts. For example, Millie *et al.* (1997) proposed detecting blooms using photopigments and absorption signatures of *G. breve*, an approach that relies on G. breve's distinctive pigment signature.

Managers need to focus on uncovering more about the basic ecology and biology of *G. breve*, together with more information about the physical and geological regimes in the Gulf of Mexico, before addressing control issues. Perhaps it is time to take a step back and address the more fundamental issues. For example, there is still no agreement or standard definition of what a bloom is in the first place. How are blooms defined, and when do they become harmful? (Smayda 1997). More long-term studies and data sets are needed to assess the dynamics of blooms, and new approaches to the data are sought. As demonstrated throughout this paper, scientists have been asking many of the same vexing questions for years. Why and how do blooms occur? Perhaps chaos theory can offer new insights into these questions of what *G. breve* blooms are all about. Using new approaches like chaos theory would also mean a shift in the way blooms are perceived – rather than seeing them as harmful nuisances and approaching them as isolated events, they would be treated as the natural phenomena inherent to the Gulf of Mexico ecosystem that they are.

PART 2: PUBLIC INFORMATION / JOURNALISM ISSUES

The effects of Florida red tides extend into the public arena as well. This section addresses how newspapers cover red tides. It is a significant issue because sensationalized news reports can "result in the potential Florida visitor remaining at home or going elsewhere to spend his vacation" (Steidinger 1973). Studies on the effect of science news on the public are scant, but it has been shown that many people rely on the mass media for their science information (Steinke 1995). It has also been shown in recent surveys that the primary news source for most Americans is the newspaper (for example, see http://www.usatoday.com/life/cyber/tech/ctc882.htm). Newspapers often serve as the primary communication link between scientists and the public but the problem is that the press frequently fails to enhance public understanding of science issues (Nelkin 1993). The public needs accurate, adequate science information to make justifiable, informed public policy decisions regarding science and society. Because red tides have become a part of what it means to be a Florida citizen – much like understanding hurricanes as an inherent, natural part of the Florida ecosystem – they need to be adequately understood. In the following section, background information about the news value of red tides, media theory, and the tension between scientists and journalists will be addressed, followed by a brief case study and an extensive historical analysis of red tide coverage by the *St. Petersburg Times.*

A. The News Value of Red Tides

Red tides recognizably affect the local environment by way of marine animal kills and water discoloration. They potentially cause public health problems such as respiratory irritation or neurotoxic shellfish poisoning (NSP), and also inflict damage on the local economy by averting tourists and potential beachgoers from area businesses, motels and restaurants. Given these effects, many traditional journalistic news values pertaining to the red tide story come to light: proximity, timeliness, size of the audience and consequence. The seemingly escalating effects of red tides on the environment, economy and the public (Hallegraff 1995) make them a significant public information issue that demands accurate, responsible reporting.

1. Public Health

Fish, invertebrates, seabirds, dolphins and manatees are not the only organisms that can be affected by a red tide. Red tides caused by *Gymnodinium breve* (*G. breve*) also have human health implications that bolster its significance as a public information issue. At least 9 toxin derivatives produced by *G. breve* are at the root of these human health problems (Baden 1989). Three types of health hazards exist: neurotoxic shellfish poisoning (NSP), respiratory irritation, and contact irritation (Hemmert 1975).

Until a 1975 publication by Hemmert in which he summarized the public health implications of *G. breve* red tides, "the world's scientific literature [provided] virtually no discussion of *Gymnodinium breve* and related public health problems." Qualitative evidence was tossed around, but little quantitative information was documented. Among the first qualitative reports in the scientific literature were the following: Taylor provided the first written report of respiratory irritation in 1917, and Gunter *et al.* (1947) and Woodcock (1948) provided similar health-related accounts about red tide events that occurred later in Florida's history when the causative organism was finally identified (Davis 1948). Why has the literature store been so scant? Part of the answer is that the association between getting sick from eating Florida shellfish that had filtered the cells containing the *G. breve* toxin was not made until the mid-1960's. Nevertheless the literature available today on this subject is still relatively scant outside of a few key references that are repeatedly described in various scientific manuscripts. Following is a brief discussion of each of the 3 health hazards implicated in *G. breve* red tide blooms.

a. Neurotoxic shellfish poisoning (NSP)

Neurotoxic shellfish poisoning (NSP) is one of the 4 types of shellfish poisonings. The other 3 are paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and diarrhetic shellfish poisoning (DSP). Cases of NSP have only been reported in Florida, North Carolina, near Campeche, Mexico (Steidinger 1993) and possibly Texas, and only 10 cases were documented between 1972 and 1993. In 1972 Florida began a shellfish monitoring program (Steidinger 1993) and in 1985 a Biotoxin Control Plan following FDA guidelines was established. That is not to say that other NSP cases have not occurred; only those cases *investigated* are documented. Given the hallmarks of NSP, which include various gastrointestinal symptoms, it would not be surprising to find that many cases of NSP have been misdiagnosed. NSP symptoms are also remarkably similar to those evident in ciguatera poisoning, also known as tropical fish poisoning. In their early histories, a lot more was known about ciguatera poisoning than NSP, and this, too, is and was likely to make NSP diagnoses difficult. It is also significant that NSP is not a CDC-reportable disease.

Furthermore, "excepting a report in the 1954 lay press, more than 80 years transpired without scientific discussion of neurotoxic shellfish poisoning" (Hemmert 1975). Eldred *et al.* (1964) reported preliminary studies on NSP poisoning relating shellfish toxicity to *G. breve* cell counts. McFarren *et al.* (1965), among the first to describe the *G. breve* neurotoxin as "ciguatera-like," also provided significant evidence of a connection between *G. breve* red tides and human illness. They reported 5 well-documented cases of NSP and 14 others that were not as well substantiated. Basic symptoms included numbness and tingling in the face, hands, and feet.

Ten years after the report by McFarren *et al.* (1965), Hemmert (1975) reported 3 cases of NSP after the 1973-74 Florida red tide. Two people had eaten steamed clams from Sarasota, Florida; the third ate well-cooked quahog clams from Englewood, Florida.

Documentation of these cases expanded the symptomology list provided by McFarren *et al.* (1965) to include stomach aches, headaches, paresthesia (hot feels cold and vice versa; described as feeling like "cold rain"), loss of balance, and a sensation of paralysis. Pupil dilation, mild diarrhea, and ataxia were other symptoms documented in the literature. The most severe symptom in Hemmert's report occurred in a 10-year-old boy who experienced convulsions, a coma, and eventually respiratory arrest. In all of the cases Hemmert discussed, everyone recovered without experiencing any residual effects. No one has ever been known to die from NSP.

Most of the following general information about NSP was taken from a chapter on toxic dinoflagellates (Steidinger 1993) in *Algal Toxins in Seafood and Drinking Water* . Brevetoxins tend to accumulate in the gut and hepatopancreas of various shellfish including oysters, hard clams, surf clams, sunray venus clams, and coquinas. Bay scallops are also known to filter the toxins, but most people only eat the adductor muscle (the toxins do not accumulate in the adductor), so bay scallops have not been directly associated with NSP. It can take less than 24 h for shellfish filtering in the presence of a *G. breve* bloom to become toxic to humans, and it takes about 6 weeks for the shellfish to purge themselves of the toxins.

Furthermore, Florida closes shellfish beds to harvesting when concentrations exceed 5,000 *G. breve* cells/l of seawater. *G. breve* is typically found in Gulf of Mexico waters at concentrations less than about 1,000 cells/l, which is considered background. The closures have been known to last several months depending upon the duration and intensity of the red tide bloom.

b. Respiratory irritation

Respiratory irritation is one of the hallmarks of a *G. breve* red tide bloom. It occurs when the wave energy along the surf breaks up fragile, unarmored *G. breve* cells and causes aerosolization of the toxin (Pierce *et al.* 1989). The odorless irritant causes coughing, tearing and rhinorrhea (irritation of nasal passages), and asthmatics are particularly susceptible. In a study by Asai *et al.* (1982) 80% (12 out of 15) of the asthma patients tested experienced an asthmatic attack after exposure to airborne red tide toxins. Moving indoors to an air-conditioned room, or wearing a surgical mask or bandana quickly abates the symptoms, and no permanent physical damage from the irritation has ever been reported.

Much of the information about respiratory irritation was largely anecdotal and qualitative prior to the study by Perez-Cruet (1986). Perez-Cruet isolated red tide toxins using high-performance liquid chromatography (HPLC) techniques. He performed experiments using canine tracheal smooth muscle and hypothesized that the alcohol component of the toxin is responsible for respiratory irritation and related bronchoconstriction in humans. His study was one of the few experiments reported dealing with the specifics of how red tides affect respiration. In another noteworthy study, Pierce *et al.* (1989) described how brevetoxins become concentrated in sea surface foam, jet drops and aerosol by the action of breaking waves, and subsequently cause respiratory irritation. Toxin concentration was shown to be 20-50 times greater in jet drops and aerosol than in surrounding seawater, and 3-5 times greater in foam than in surrounding seawater.

c. Contact irritation

Very few references regarding contact irritation exist in the literature. Contact irritation includes symptoms such as dermatitis or conjunctivitis (Hemmert 1975) but the information available on contact irritation is anecdotal at best. Some beachgoers and divers in wet suits have reported these symptoms after exposure to *G. breve* waters, but it varies greatly from individual to individual.

2. Economy

"Unquestionably its greatest impact on man is economic" (Habas and Gilbert 1974). This quote highlights the news value of red tides, and illustrates how many newspaper articles about red tides have focused on the economic angle.

Documenting the effects of red tides on Florida's economy is a difficult task. Estimates of beach cleanups alone vary considerably; according to one newspaper report (*St. Petersburg Times*, October 18, 1972), the 1971 red tide cost Pinellas County about $250,000. Estimates should be regarded with caution because many variables exist in every individual's perceptions of his or her own financial situation and that of the community at large.

Reviewing the few quantitative estimates that have been done leaves many questions. For example, most sources interviewed for these losses were hurt economically by the red tide (that is, many local beach communities suffered from slashes in tourism revenue), but these studies do note examine if other Florida businesses boomed during red tides. Beach visitors undoubtedly declined, but it is possible that these would-be beach visitors then patronized the local amusement parks, zoos and museums? Questions such as these highlight the need to treat economic estimates of red tides cautiously and skeptically. Following is a brief review of the estimates that have been published in the scientific literature.

Habas and Gilbert (1974) were among the first to perform an economic assessment of a Florida red tide. They used data from an intense 1971 red tide that lasted about 4 months, but attracted widespread attention and negative publicity. Relying on personal interviews, newspaper clips, and studies from the Florida Department of Commerce and Business Regulation, Habas and Gilbert conservatively estimated a total loss of $20,000,000 to 7 counties along Florida's west coast. They projected that a more severe red tide could inflict 3 times as much economic damage. The economic losses lasted about 50 days after the red tide ended, and the hotel/motel industry sustained the greatest losses ($6,000,000). Augmenting the notoriety of this particular red tide was the fact that newspapers failed to report the good news that the tide ended in August; only the negative news about the tide's presence was announced in the headlines; Habas and Gilbert considered this the main reason for the financial woes inflicted by the 1971 red tide.

Habas published another estimate of a Florida red tide in 1975. He conservatively assessed the damage on the tourist industry alone during the 1973-74 red tide to be about $15,000,000. This red tide occurred predominantly in the winter months when tourists typically flock to Florida; damage to the tourism industry was severe. Like the Habas and Gilbert study (1974), 7 Florida counties were included in the study. Complicating Habas' study were two other factors that inflicted damage on Florida's economy during the red tide: a gasoline shortage and high interest rates.

Furthermore, while the 1971 red tide was relatively short, moderately severe, and widely publicized, the 1973-74 red tide was relatively long, widespread (reached north to Panama City and Pensacola) and moderate. It was not as widely publicized as the 1971 red tide so Habas assumed that the economic damage was due solely to its duration; it was the bloom that did not seem to have an end.

A paper by Jensen (1975) dealt primarily with the 1972 New England *Alexandrium* (*Gonyaulax tamarenses)* red tide but its main conclusions were, and are, readily applicable to the economic woes that surface during Florida *G. breve* blooms. Jensen's publication is widely referenced for its coining of the phrase "economic halo," the effects that publicizing red tides have on the economy. In the words of Jensen, "the halo effect touched almost all seafood as the buying public over-reacted"; the public avoided more seafood than those types specifically affected by the bloom. The study is significant because it highlighted the need for improved media coverage and increased public awareness of red tides. Many seafood companies even felt compelled to take out full-page advertisements in local newspapers to clarify that their seafood products were unaffected by the red tide. Rumors and misinformation abounded in this New England bloom – problems that signify the media's power to perpetuate, expound, or (hopefully) handle them responsibly.

The Florida Sea Grant Program recently (June 1999) conducted a workshop of scientists, businessmen, managers, and citizens' groups to develop an assessment protocol to obtain meaningful economic data to interpret. These data would serve as indices of economic impacts incurred Florida red tides.

3. Effects on Public Policy

The amount of coverage devoted to the red tide issue can potentially affect public policy as well. Preliminary investigations show that the more red tides hit the media headlines and soundbites, the more citizens' groups are formed. For example, the Citizens Advisory Committee on Red Tide was reported in a *St. Petersburg Times* article on April 20, 1963. A group known as START (Solutions To Avoid Red Tide) is a more recently formed group that has also received a fair amount of press coverage. As their name implies, members of START are dedicated to finding responsible ways to combat red tides. Furthermore, as red tides are a hot news item, they are also a hot research item because a lot is yet to be learned about their fundamental biology and ecology; more and more research proposals are submitted to work on red tide-related questions. In turn, this potentially means more press coverage, and the cycle continues.

4. Other

Red tides are a significant public information issue that demands accurate, responsible reporting. What will unfold in the following analysis, however, is that newspaper coverage of Florida red tides in the *St. Petersburg Times* has suffered from inadequacies and fallen short of journalistic ideals. Furthermore, while the primary news value of red tides lies in the public information issues that envelop them, they also present a hot science news story. Numerous research proposals for red tide research have kept scientists busy for years. In this way, red tides present added challenges for the journalists assigned to cover them; not only are their potential effects on the environment and citizenry widespread but the science behind them demands careful, thorough understanding before accurate, responsible reporting can be done.

It seems that a science writer would ideally be assigned to cover the red tide story. However, given budget constraints and other practical factors, many newspapers do not have reporters assigned solely to the science beat. Many times, those assigned to cover red tides are general assignment reporters who very well may have covered a car wreck at 1:00 p.m. and a mayoral press conference at 3:00 p.m. when "The Return of Red Tide" news release floods the newsroom fax machines. Ronald Kotulak, a *Chicago Tribune* science writer summarized the challenges of science stories well: "It's like putting together the pieces of a puzzle. Researchers themselves, because they are so busy and narrowly focused, often see only their own piece of the puzzle. The job of the science writer is to find and put together as many of the pieces as possible to provide readers with a perspective of the whole picture" (Kotulak 1997). In short then, covering enigmatic phenomena like red tides, which keep scientists buzzing with question after question, present the journalist with a considerable challenge that must be met if the public interest is to be adequately served.

5. Media Theory

The relevance of media theory to this analysis is that understanding theory means appreciating the powerful influence the media can have on the general public and its perception of reality. A theory is essentially a framework or a manner of looking at a phenomenon, circumstance, or situation in a way that has yet to be disproven. A mass communications theory is basically a framework through which researchers view the mass media in an attempt to better understand the innumerable factors that play a part in the communication process at large. In the words of one mass communications theorist, "the point of theorizing is to understand ... theory permits us to describe and perhaps explain what is going on more tidily and comprehensively" (Inglis 1990).

The complexities of mass media theory need not be discussed here. The point is to recognize its relevance and significance. "Although communication research scholars have not reached a full understanding of the impact that mass media are having upon the psychological, moral, economic, political, creative, cultural, and educational aspects of the ordinary individual's life, they have begun to accumulate a base of research findings that will increasingly aid in understanding these issues" (DeFleur and Ball-Rokeach 1989). When it comes to science, recognizing the power of the media becomes particularly important because most people rely on the mass media for their science information (Steinke 1995). How journalists translate science in the newspapers become the reality of science for many readers. It is imperative, therefore, for journalists to cover science issues, including red tides, as responsibly and accurately as possible.

Many different factors are at work in the reporting of news; some have the potential to skew the news. As gatekeepers of the news that is and is not important to society, journalists have a tremendous influence on the way community members view their society. The choices made at every level – individual, editorial, organizational – pave the path down which the daily news travels. Multidimensional and multilevel paradigms operating in every news institution influence the decisions that shape the reality that hits the front page of the newspaper. Recognizing this is critical to understanding the complexities at work in any news report, science-related or not.

B. Tension Between Scientists and Journalists

How well do scientists and journalists communicate? How well are articles written in the newspapers? How does the public perceive the information? Does it help their understanding or ultimately hinder it with conflicting reports and inaccuracies? Closely examining the lines of communication that connect scientists, journalists and the public would provide some background before these questions are answered. Various researchers have described the tension that often exists between scientists and journalists; ironically, it is a tension that causes problems even though accurate, responsible communication of science information is the goal of both parties (Friedman *et al.* 1986; Dunwoody 1986; Burkett 1986; Nelkin 1993). "As the interest of the media in science has blossomed, scientists have been drawn into the science communication process. Some have resisted strongly, but others have welcomed the chance to share their information with people outside the scientific community" (Friedman *et al.* 1986).

The differences generally stem from the different audiences scientists and journalists intend to serve. Scientists are specialists writing for an elite audience and journalists are generalists writing for a mass audience. While readers of a scientific journal article analyze the minute twists and turns of every article in their field of interest, "readers of a newspaper science story will read for only a few main points. To burrow into methodological or theoretical detail is to lose them, for most of these readers will be interested primarily in what the researchers found and why it is important to their daily lives" (Dunwoody 1986). Also, whereas a journalist cherishes immediacy, "scientists fear prematurity in disclosure of their knowledge until their data, procedures, and conclusions have been studied by their peers and published in an approved way" (Burkett 1986). These factors, combined with the space and time constraints of journalism, make science coverage especially challenging.

In *The Ethical Dimensions of the Biological Sciences* Dorothy Nelkin (1993) closely examines the tension between scientists and journalists in an essay called "The High Cost of Hype." She writes:

> Perhaps the most important source of strain between scientists and journalists lies in their differing views about the appropriate

> role of the press. Scientists often talk about the press as a conduit or pipeline, responsible simply for transmitting science to the public in a way that can be easily understood. They expect to control this flow of information to the public as they do within their own domain. ... They are reluctant to tolerate independent analysis of the limits or flaws of science. They assume that the purpose of journalism is to convey a positive image that will promote science, and they see the press as a means of furthering scientific goals. ... Scientists tend to attribute negative public attitudes about science and technology to problems of media communication, ultimately to journalists, who, they believe, distort the flow of information from scientists to the public.

It is likely that many scientists hold this image of journalists because science coverage has often been characterized by "gee whiz," breakthrough reporting that fails to adequately explain the complexity normally entangling science and the scientific process. A prime example occurred in 1989 when the press made the idea of cold fusion sound like it was the answer to all of the world's energy problems. As it turned out, no one could duplicate the work of the cold fusion originators, and the work was cast aside as scientifically inaccurate. The press coverage was often dramatic and sensational. These cases of premature excitement perpetuate the negative perception of the press held by many scientists.

"The journalistic preoccupation with conflict and aberration, intended to attract the reader's interest, is a further source of strain" between scientists and journalists (Nelkin 1993). Scientists have long criticized the media for boiling down the weeks, months, and years of research efforts into a few sentences omitting meticulous details that make scientists tick. Furthermore, some scientists are difficult to deal with as news sources (Bennett 1986). Bennett wrote that in the words of "Victor Cohn's wonderful dictum, 'Scientists are to journalists what rats are to scientists.'" Many scientists are also upset with past stories in which they were blatantly misquoted. In short, then, science journalism is a niche that is hungry for diligent, aggressive journalists who must understand how science works in order to convey it responsibly.

Despite these apparent differences between science and journalism, the two institutions are remarkably similar. For example, both traditionally disdain bureaucratic intrusion and demand honesty and integrity. They have a duty to seek out the truth and serve the public in a democracy that demands responsible behavior by both. Also, some examples of journalistic ethical values that science also cherishes are truthfulness, trustworthiness, stewardship, autonomy, and doing no harm (Reiser 1993). Each institution values accuracy, objectivity, and healthy skepticism. Furthermore, both institutions have recently witnessed a surge in public attention regarding questionable ethical standards and have each been criticized for not meeting the demands of adequate professional norms. Because credibility is the lifeblood of both institutions, lack of public support renders them impotent; each must therefore stand up to the test of publicity. In short then, science and journalism are two institutions with keen differences they readily recognize, striking similarities they sometimes fail to see, and a need to improve accountability in an atmosphere of increasing public distrust.

C. 1980 Case Study - Jacksonville, Florida

The following Florida red tide story about a frenzied public response to media reports and public hearsay epitomizes the need for responsible, accurate science reporting. It draws attention to many problem areas in science reporting in general, and holds many particular applications to the reporting of natural events such as red tides. Many felt the anxiety-ridden public reaction to the events that occurred in Jacksonville were heightened by the media's treatment of the event – some went so far as to call it "garbage journalism." While it seems easy to point a finger at the media, the story offers an opportunity to closely examine media practices and the avenues of communication used during crisis events so that recommendations for improving coverage can be made.

The following account is adopted from a collection of summaries and news articles stored at the Florida Fish and Wildlife Conservation Commission in St. Petersburg, Florida as well as personal communications with researchers who recall the 1980 event well. A brief analysis will follow the story.

1. The Story

"It came like a phantom," described an article in the *Sentinel Star* on December 7, 1980. "Appearing and disappearing silently, enveloping the beaches from Duval through Brevard counties like an invisible shroud of fear. Unnamed."

It was the middle of November, 1980. Officials from the Marine Patrol contacted the Bureau of Marine Science and Technology about a mysterious mist in the Jacksonville Beach area. Beachgoers complained about watery, stingy eyes and sore throats. But the symptoms were not wholly consistent with the signature of a red tide. For example, fish kills and coughing were not reported; if it *were* a red tide caused by *Gymnodinium breve*, these would have ranked at the top of the list of tell-tale signs. And besides, most red tides occur along Florida's west coast. The only red tides known to have occurred on the east coast of Florida were in 1972 and 1977; these were rare events that occurred because the Loop Current and Florida Current transported a west coast bloom around the Florida peninsula. A red tide in Jacksonville would be highly unlikely, given what researchers knew about how red tides worked at the time.

The mist was soon reported down to Flagler County. "Noxious Mist (on) Beach," warned a large sign on State Road 402 heading toward Playalinda Beach. Anxieties simmered. What was going on? It was time for Jacksonville officials to ask for outside help.

Among those called was Beverly Roberts from the St. Petersburg Department of Natural Resources Marine Research Laboratory (DNR, now part of the Florida Fish and Wildlife Conservation Commission). She assisted with plankton samples to test the possibility of red tide, and she felt that possibility was a likely one. By late November, the Center for Disease Control (CDC) and officials from the Environmental Protection Agency (EPA) were involved; they, too, suspected red tide. Red tide was no longer an *unusual* suspect.

By this time, various forms of respiratory irritation were reported, including coughing. However, no fish kills were observed and many plankton samples taken by some agencies turned up negative. The mystery continued and debate ensued as to its solution.

Public reactions spanned the spectrum from wild overreaction to nonchalance. Some experienced eye irritation. Some sneezed. Some felt nauseous. Some coughed. Some did all of the above and ran to the emergency centers fearing they were poisoned or gassed. Others, including one local Jacksonville scientist, said it was acid rain. Still others didn't have any problems at all. Sea gulls were dying. Diesel fuel was found in the water. Some suspected chemical pollution. Or maybe NASA misfired one of their missiles, and that was the cause of the mist. Others thought nerve gas in the deep Atlantic, and feared a government cover-up. They insisted that Jimmy Carter and former Soviet Premier Nikita Khrushchev were having a secret meeting in a Russian sub about two miles off the coast trying to decide where to bury old nerve gas off Florida's coast. Some even pointed to the heavens. Martians, they said.

On the advice of Dr. Steidinger in St. Petersburg, Jacksonville officials wore surgical masks along the beach; if the irritant was particulate (like red tide) instead of gaseous, the masks would filter out the particles and they should not have any trouble breathing.

The masks worked, so it was confirmed that the irritant was particulate. Then a fish kill was reported at New Smyrna Beach. OK, officials said. It had to be red tide. Sigh of relief – no nerve gas, no acid rain and no Martians.

Sure enough, DNR notified EPA and the Volusia County Health Department that yes, it was red tide – the first outbreak reported on the northeast coast of Florida. Within 2.5 hours, shellfishing areas were closed, the press was notified, and a hypothesis for this unprecedented phenomenon proposed. Experts theorized that an unusual recipe of currents, eddies and a warm water Gulf Stream intrusion probably transported a red tide from Florida's west coast up Florida's east coast. The mist that hugged the shoreline was most likely caused by warm water and cooler air, they said.

But the ballooning concerns about chemical dump sites and nerve gas were still reported by certain media and therefore manifested in daily public discussions. Paranoia followed suit. It came from more than 200 miles offshore in the deep Atlantic, they said. If it were just a red tide, why weren't there more fish kills? Why did some of the samples still turn up negative for red tide? The hysteria mounted.

On December 9, a multi-agency press conference was finally held so clarifications could be made and nerves settled. It wasn't a government cover-up. It wasn't nerve gas. It wasn't anything unnatural. Unusual, yes, but not unnatural, experts emphasized. It was red tide.

2. The Analysis

The dramatic way in which the Jacksonville story unfolded serves as a powerful reminder for journalists to report events such as red tides as accurately as possible. It is a testament to the fact that red tides constitute a significant public information issue. Many physical phenomena are still inadequately understood from a scientific perspective; from a journalistic perspective, then, they warrant keen, extra careful, accurate reporting. It turns out that one reason the toxin was not found in the samples tested was because the samples were frozen or preserved, and at the time officials tested live samples. Nevertheless because it seemed no one had an immediate answer regarding the mist, the media reports assumed tremendous power in shaping public perception of the reality of the event. In addition to deserving the facts, the public needed context to be able to place the event in its proper perspective.

The definition of accuracy given by Black *et al.* (1995) in a handbook called *Doing Ethics in Journalism* serves as basis for this discussion:

> "Accuracy means 'getting it right.' It is an essential responsibility of individual journalists and news organizations. To provide wrong information is a disservice to the public and a sure way to erode the credibility of journalism. ... To be sure, journalism can never tell the full truth in every story, because facts compete against each other, and additional facts and more information emerge over time. Many stories must be reported piecemeal, as they develop. But the fuller picture will only come from journalists committed to the fundamental principles of accuracy and fairness."

In today's atmosphere of increasing public distrust of the press, accuracy means more than just getting it right. Expanding upon the definition by Black *et al.* (1995), implicit in the word "accuracy" lies the innate responsibility of the journalist to get it right *within the proper context*. This is true for all news stories, but it holds especially true for science stories; it is generally safe to assume that most members of the general public are ill-prepared to read science stories as critically as they should. Most do not have a sufficient scientific background to make informed policy decisions, let alone make judgments about the hypotheses being tossed about in the scientific arena regarding various environmental phenomena. The journalists assigned to cover these stories should keep this in mind and seek out the necessary sources to provide as much context and explanation as possible within the inherent journalistic constraints of time, space, and editorial decisions.

Based upon the articles available for analysis on this story, it seems that most of the journalists covering the Jacksonville story did basically get it right. They reported the atmosphere of panic and distrust in the Jacksonville community, and did so accurately. "Far-out tales ride on red tide," read one headline in the *Sentinel Star* (December 15, 1980). The best reports were those that provided context along with the facts of the situation at hand. The best reports were also those that were not swayed by the sexy nature of a noxious mist swallowing up a community, or the possibility of a government cover-up. They might have included these details as just that – ancillary details – but the best reports did not sensationalize them or allow them to color their stories to the point of obscuring the truth.

For example, an article by Kathy Connor in the Jacksonville *Times-Union* newspaper had the headline, "Mist-nerve gas rumor labeled 'lasciviousness.'" The nerve gas rumor seemed to spread through the public discourse like a bad flu; the only remedy was to address it in the newspaper. Connor went through the extra effort of amassing details about the nerve gas story. She reported them accurately and in context. Apparently, it was true that in 1970 the Army had obsolete nerve gas it needed to dispose, and the site chosen was nearly 300 miles offshore Florida's Atlantic coastline. This in itself constitutes a story with a tremendous public information value; however, the events were in no way connected to what amounted to a natural red tide event occurring off the Jacksonville coast. It was apparently a case of a comment that turned into a rumor, which then turned into a news angle that was given too much play in some

Florida newspapers. On the other hand, Connor devoted a considerable amount of column inches to explaining this background story in great detail. Supplying sufficient detail was necessary to quell the public fear of a horrifying possibility, and Connor upheld the journalistic ideal of reporting the truth. She provided a significant public service by doing so, and quickly stated in her lead that the possibility of the nerve gas being associated with the mysterious mist was deemed "garbage journalism."

However, rumors about the nerve gas were still flying around in the realm of public discussion. Some newspapers *were* too quick to report the nerve gas reports as more factual than they actually were. Here the tremendous power of the media to influence and perpetuate public perception or misperception of reality comes to light. For example, a central Florida newspaper that went unnamed in Connor's story apparently skewed the facts and placed unwarranted emphasis on the possibility of a nerve gas leak without providing context. In doing so, it failed to report the truth as accurately as possible. The story may have been accurate in terms of quoting the source of information, an official from the Environmental Protection Agency, but it was inaccurate in the way it treated the quotes, and any quote taken out of context has the potential to skew the original meaning. Context is critical.

Furthermore, as Black *et al.* (1995) emphasized, many stories are reported piecemeal, and the facts change with time. When it comes to potentially alarmist reports and hypotheses pertaining to a particular event like the mysterious mist, journalists covering the story must take extra precaution to be skeptical, to seek out multiple reliable sources, to ask lots of questions, and to exercise keen responsibility in their reporting.

The Jacksonville story raised another concern that warrants discussion. While some articles were sensational and inflammatory, others raised awareness to serious flaws in the scientific process, such as the apparent lack of organization within and between the scientific organizations called in to handle the science behind the crisis. "Hazy agency coordination revealed in mist investigation," read one headline (*Sentinel Star*, December 7, 1980). Therefore, for the scientific agencies involved, the Jacksonville case was a hard-learned lesson on the importance of not only communicating clearly and effectively with the media in events such as red tides, but also maintaining open communication with each other so that media reports are consistent. The event highlighted the importance of coordinating agency efforts in this regard for the benefit of the community at large, let alone the agencies themselves.

D. Newspaper Analysis (*St. Petersburg Times*)

Following is a comprehensive analysis of the newspaper coverage of Florida red tides from 1953 to 1997 in the *St. Petersburg Times.* The analysis revealed a wide spectrum of inadequacies in red tide coverage from alarmist stories to blatant scientific inaccuracies. About 500 red tide articles were analyzed of about 639 that exist (77% of the total number of red-tide related articles written between 1953 and 1997). The year 1953 was chosen as the starting date because that is when comprehensive card catalog information was started at the St. Petersburg Public Library (3745 9th Avenue North, St. Petersburg, FL 33713). Microfilm was used to view all articles from 1953 to 1987. A CD-ROM database located in the University of South Florida's St. Petersburg campus library was used to track coverage from 1987 to 1997. Visits to news clip library at the *St. Petersburg Times* (490 1st Avenue South, St. Petersburg, FL 33701) confirmed that the analysis was comprehensive.

The analysis includes general assessments of the accuracy, context, and overall journalistic merit regarding the coverage spanning 1953 to 1997. The following sections are discussed: summaries by decade, choosing the right words, technicalities/grievances, lifted quotes, use of photographs, science-fiction or otherwise questionable headlines, questionable sources, good examples, and recommendations for improving coverage. Appendix 2 provides a comprehensive listing of all descriptions for red tide used throughout the coverage; it will be referenced often throughout the ensuing discussions.

1. Summaries by Decade

It is extremely difficult to make sound quantitative interpretations of the relationship between the number of articles written in a particular year and the duration in months of the red tide (Figure 2. It seems reasonable to conclude that no *direct*

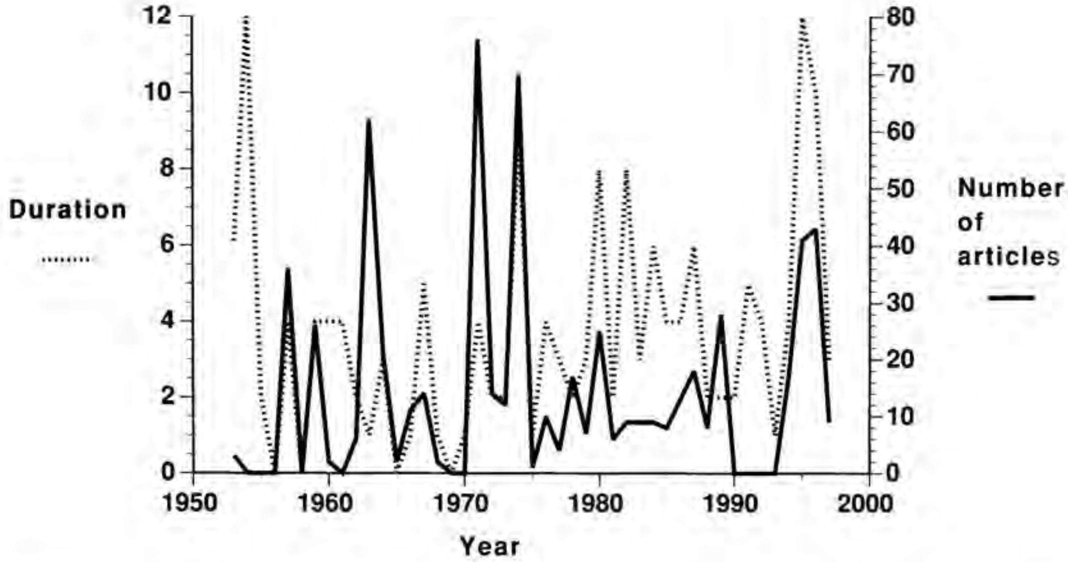

Figure 2. Number of articles written per year and the duration of the concurrent red tides.

correlation exists between the number of articles and the red tide duration. For example, even though the red tide in 1971 only lasted about four months, more than 70 articles were written. In this case, the greater the public impacts in the way of economic and health impacts, the greater the coverage. This particular red tide also heavily impacted the Tampa Bay estuary, which is unusual. 1971 happened to be a drought year, so salinity levels in Tampa Bay were high enough to support the red tide bloom. Furthermore, the earlier estimates may be skewed by the fact that the *Times* had an evening newspaper called the *Evening Independent*; coverage by that edition was not included in this analysis. It seems more probable that a stronger correlation exists between red tide *intensity* and number of articles written but a host of factors play into the daily news decisions of what to print and how to print it.

Following is a brief discussion of the decades covered in this analysis (1950's - 1990's), including general information about the trends and characteristics of each. Each decade of coverage was marked by a discernable set of trends and characteristics. The summaries provide a general overview of how the coverage of the red tide issue has progressed through the years.

a. 1950's

The organism that causes Florida red tides was not scientifically identified until 1948 (Davis). Therefore, newspaper coverage in the 1950's reflects some of the earliest attempts to translate what was known about the science behind the phenomena for a general public audience. Overall, the early newspaper accounts devoted a relatively generous number of column inches to the red tide story (Table 8), and provided valuable information placed in context for the reader.

Table 8. 1950's Red Tide Articles in *St. Petersburg Times*

Year	*Number articles*	*Number analyzed*
1953	3	3
1957	36	36
1959	26	26

The following trend was observed in articles written throughout the early and mid-1950's. Each article was subdivided into bold-headed categories such as the following: 6,000 PER MILE, CONDITION WORSE, CREWS PITCH IN, and AERIAL SURVEY. These sub-headings made the articles easy to read and rendered the articles comprehensive and informative. The information provided specifically denoted which areas were affected by red tide and what was known scientifically at the time.

The 1950's marked the beginning of other trends that would characterize red tide newspaper coverage for many years to come. An example is the way the media described the red tide phenomena. Journalists are in the business of distilling technicalities for a mass audience within their constraints of space and time. As a result, they often generalize. For example, throughout the coverage analyzed, they typically used general terms to describe red tide: "the fish killer," "fish-killing organisms," or "a plague that kills fish." These blanket phrases were the rule rather than the exception, and details about the phenomena were inevitably lost when the blanket phrases were used. The particular species of fish affected by a particular red tide, for instance, were rarely, if ever, mentioned. "The fish killer" seemed to be the most frequently used description; it was more popular in the 50's and 1960's, but it was used more than a total of about 70 times between 1957 and 1997 (see Appendix 2).

Another nontechnical name for *G. breve*, coined in 1957, was quoted often in red tide-related articles primarily in the 50's and 1960's. The media called *G. breve* (then called *Gymnodinium brevis*) "Jim Brevis" for short. Giving *G. breve* a humanistic name was presumably an effort to distill the scientific nature of the phenomena into understandable, familiar terms that the public would more easily digest. It is important to recognize that newspaper reporting during the 1950's and 1960's was characterized generally by more colloquial and folksy language.

Furthermore, many 1950's articles referred to the red tide phenomenon in a purely pessimistic way. As shown in Appendix 2, descriptive phrases such as the following were used: "a tiny marine pest," "a stinking situation," "the red tide scourge that has menaced us for a decade," or the "red tide bugs." Given the health-related nuisances and economic plights sustained during or in the wake of red tides, it is natural to assume that the public would look distastefully upon them. However, it was postulated at the time (and is now confirmed) that red tides are a natural phenomenon to which the Gulf coast ecosystem responds with resiliency – one theory even holds that they actually benefit the ecosystem by periodically increasing its productivity. Rarely were red tides addressed in this manner, presumably because red tide ecology was (and still is, in many respects) largely unknown in the research community. It is nevertheless possible that the negative descriptions and attempts to humanize the phenomenon skewed public perception of the event in the early years of coverage.

Furthermore, one of the major subjects of red tide news coverage in the 50's was copper sulfate ($CuSO_4$), a chemical used in an attempt to control and eradicate blooms. Almost half of the articles published in 1957 mentioned $CuSO_4$. Officials sprayed tons of $CuSO_4$ from crop-duster planes and dragged it behind boats along various west Florida coast beaches, even before sufficient research and testing on the chemical was completed. As it turned out, the $CuSO_4$ was only effective in killing off blooms for about two weeks. It was expensive and its lethality was not specific to *G. breve* – it killed other forms of marine life as well, and therefore disrupted the natural balance of the ecosystem. It was also later determined that killing *G. breve* cells causes them to lyse so their toxin is released into the water anyway.

An interesting characteristic of the 1950's coverage emerged from the analysis. Many articles were accompanied by maps showing the approximate extent and location of the red tide bloom – a signature of responsible journalism. The coverage overall would have benefited from more of these types of maps so beachgoers did not avoid more areas than were actually affected by the red tide.

In summary, coverage of red tides in the 50's was reasonably well done. Hindsight makes it relatively easy to critique some of the science reports now recognized as scientifically inaccurate. For example, many articles referred to rain as a primary contributor to red tide blooms, which is not necessarily the case. Many articles also referred to the "rapid reproduction" of cells during blooms when in fact, the growth rate of the causative organism does not change and is actually slow. A handful of articles could also be criticized for being premature; they were borderline breakthrough-type articles that are often best for reporters to avoid because very few actual breakthroughs occur in science. One example was an article published on October 9, 1957 with the following headline: "Solution Seen Soon in Red Tide Outbreaks." The use of $CuSO_4$ seemed to raise false hopes that it was a sure cure, which in fact it was not. Considering that today any solution remains elusive, "solution seen soon" was clearly an overstatement.

b. 1960's

The significance of red tides as a public information issue gained momentum in the 1960's (Table 9). In one notable report, three Florida mayors (Indian Rocks Beach, St. Petersburg Beach, Madeira Beach) requested that the red tide sampling flights be discontinued (9/26/62: "Shhh! No Red Tide Talk, Huh?"). It seemed that many felt it better if they simply did not hear about it even though it remained the duty of the media to report it. Complaints that media reports made the red tide situation worse were not uncommon.

Table 9. 1960's Red Tide Articles in *St. Petersburg Times*

Year	*Number articles*	*Number analyzed*
1960	2	2
1962	6	6
1963	62	62
1964	21	20
1965	2	2
1966	11	10
1967	14	0
1968	2	0

Overall, red tide coverage in the 1960's was accurate and responsible. One significant and positive aspect of the articles analyzed was the fact that many reported if red tide was subsiding, or if it wasn't much of a threat. In the 1960's, this was considered news. However, based upon the coverage at large, it is true that considerably more media attention is given to the beginning of a red tide than to its end, impacting beachfront businesses and restaurants whose revenue often rely upon sunny Florida media reports. Neglecting to report the end of a red tide is arguably a mark of irresponsible journalism (which was the case in coverage analyzed other than the 1960's).

Many other positive trends emerged from the analysis of red tide coverage in the 1960's. For example, more articles effectively addressed the health effects of red tides (for example, 4/17/63: "Health Aspects of Red Tide to be Aired"), a critical public information issue. Also, scientific research studies on red tides were often documented in the newspaper, thus offering the readership the latest scientific information in addition to the relevant public information issues such as fouled beaches. One example was a fairly extensive article written about research on the possible role of Vitamin B_{12} in red tide blooms (4/6/63). It was hoped that learning more about this vitamin would benefit control efforts; as in the 1950's, the issue of potentially controlling red tide blooms received ample public attention in the way of media reports in the 1960's. Still another characteristic of coverage in the 1960's was the considerable number of briefs used to give periodic updates on the red tide story. Briefs were often reported instead of the lengthier, comprehensive articles that consistently characterized the 50's coverage.

Some articles in the 1960's addressed the question of the potential benefits of the red tide on Tampa Bay in terms of fishing (for example, September 10, 1963). While it is true that red tides have the reputation of killing plenty of fish, not all species are always affected. Bottom fish are typically affected first. Decimating some fish species could theoretically reduce competitive pressures on other fish or invertebrates and allow other species to flourish. These types of ecological issues were rarely addressed in the newspaper even though their significance is readily apparent. One recognizably good article by James Lewis that provided a wealth of historical and current information about red tide within context was printed on March 31, 1966. Lewis wrote at least 14 articles on red tide in the 1960's.

Furthermore, what may have been the first picture of a *G. breve* cell printed in the newspaper appeared in an article on April 6, 1963. It was a light micrograph of the tiny cell that presumably dispelled the science fiction horrors of the "fish-killing" organisms that periodically "turn the water red" along the west Florida coast, as many articles reported. The visual complemented the article. That is not to say, however, that all articles written in the 1960's avoided sensationalizing the story. For example, the following headline appeared on September 1, 1964: "Bugs' Sex Life Probed." While humorous and catchy, this headline is sensational.

Another article that warrants a brief discussion (April 15, 1963) is an example of a well-intentioned effort that went awry. A bad egg in the basket of 1960's coverage, it is important not to overemphasize but it would also be irresponsible not to mention. The article presented information about red tide in a question-and-answer format. The attempt to present summary information in bite-sized chunks was admirable, but the article as a whole suffered from inaccuracy. First, the reporter called *G. breve* an "olfactory organism" in the headline and part of his early description. However, while the effects of a bloom may be offensive to the olfactory system (that is, fish smell when they die and rot), to call *G. breve* an "olfactory organism" was inaccurate. You cannot smell the cell. The article is also alarmist in that it mentions a "killing Tide" that occurred in Australia, but did not adequately explain the difference between the red tides that occur there and Florida red tides which are caused by a different species. Lewis was also needlessly alarmist when he wrote that red tide "suffocates" fish and other marine life. The word "suffocates" connotes a certain image in the mind of the reader that is inconsistent with how red tides really work. The red tide toxin culprit does disrupt the gill function, but using the word "suffocate" without explaining it in context is arguably alarmist.

c. 1970's

The 1970's were an active decade for red tide coverage (Table 10). The particularly notorious red tide, 1971, amassed 76 red tide-related articles. It only lasted about four months, but it was severe enough to attract widespread media attention especially because it affected Tampa Bay. It remains unclear whether it was because of the greater number of media reports, but more criticisms can be made regarding coverage in the 70's than any other decade.

As mentioned earlier, many area business and restaurant owners complained that the media did a poor job of covering the red tide story and that they were to blame for a substantial proportion of lost revenues during red tides. They accused the media of being sensationalist and too general in coverage of the event, arguing that news reports

Table 10. 1970's Red Tide Articles in *St. Petersburg Times*

Year	*Number articles*	*Number analyzed*
1971	76	75
1972	14	1
1973	12	1
1974	70	6
1975	1	1
1976	10	3
1977	4	4
1978	17	17
1979	7	0

often used blanket statements regarding areas affected by a particular red tide that incurred more damage than necessary to tourism efforts.

Media complaints were fairly well publicized in the 1970's, when the tremendous power of the media in shaping the reality of scientific events like red tides came to light. The public reaction/tourist angle was the angle most evident; articles documented the fact that many people were staying away from the beaches because of the red tide (for example, 7/8/71: "Red Tide is Everyone's Problem," 8/1/71: "A Red Tide Casualty: Beach Tourist Trade"). One article (July 11, 1971) reported, "A story released by the Associated Press Thursday quotes a Longboat Key motel operator as saying that tourists would 'be crazy' to come to Longboat." It is likely that quotes such as this one reached a wealth of would-be tourists who then decided not to visit the Sunshine State, especially if such reports were carried by the wire service.

While red tides received a reasonably adequate amount of fair coverage, examples of sensationalism and other questionable journalistic practices were also evident in the 70's. These will be discussed in more detail in the ensuing sections; a few examples will suffice for now. The following are examples of sensationalist language that may have skewed public perception of the reality of the event (taken from Appendix 2): "the Red Tide's murderous attack" (8/8/71), "The Red Tide has once again showed it is no respecter of the works of man and nature" (9/5/74), the organism blooms to cause "noxious fumes that choke and gag humans" (4/7/75), and "poisonous sea creatures" (9/27/78). Another journalistic practice that emerged from the analysis was that of lifting quotes, which essentially means the journalist relies upon descriptions from earlier media reports, often verbatim. This caused problems when the descriptions used were inaccurate and otherwise less than ideal. (See Lifting quotes section).

d. 1980's and 1990's

Coverage in the 1980's and 1990's improved in terms of overall journalistic merit (Table 11). Most journalists described the event more or less accurately. There were no breakthrough-type articles and red tides were discussed in context. Relative to the prior decades, more stories in the 1980's focused on the health effects of red tides, such as human respiratory irritation and shellfish poisoning. The reports also clearly depicted where shellfishing bans were in effect. Another slant to the red tide story observed in the 80's coverage was the effect of red tides on dolphins. In 1987, dolphins were allegedly killed by the effects of the *G. breve* toxin along the Atlantic east coast, and the story (not surprisingly) received significant news coverage.

The latter point is an ideal segue into a discussion of red tide coverage in the 1990's. The most significant characteristic of the 90's coverage analyzed was the tremendous number of articles written about the effect of red tide on endangered manatees. Manatees make for a marketable story with human-interest appeal; the fact

Table 11. 1980's and 1990's Red Tide Articles in *St. Petersburg Times*

Year	*Number articles*	*Number analyzed*
1980	25	25
1981	6	0
1982	9	9
1983	9	0
1984	9	9
1985	8	8
1986	13	0
1987	18	18
1988	8	8
1989	28	28
1994	17	17
1995	41	41
1996	43	43
1997	9	9

that they are endangered and were dying amplified the newsworthiness of the story. In the spring of 1996 an unusual red tide outbreak was responsible for killing almost 150 manatees along Florida's southwest coast (Kleiner 1996). Needless to say, this event warranted news coverage not just because of its solid public interest appeal, but because the association between red tide and manatee deaths was only documented two other times in Florida's history.

Briefs represent a practical, space- and time-effective means of reporting an ongoing event such as red tides on a daily basis. In general, using briefs to report the red tide story on a daily basis became a more common practice as coverage progressed through the 70's, 80's and 90's. However, it is not surprising that briefs can be criticized for their lack of content, and this occurred quite a bit in the 80's and 90's (for example, 6/14/87). It is inevitable that a news brief fail to provide the same context that a full news story would. In terms of addressing a complex issue like red tide, however, briefs are especially challenging because they must present much information in a small space without sacrificing the accuracy of such a complex issue. It is difficult to make the decision about how much information is assumed to be general knowledge, especially when a considerable number of people reading the paper are out-of-town tourists who may be reading about red tides for the first time. In this way then, keeping the public interest in mind, briefs become a riskier means of reporting red tide information. Their form may not always fulfill the intended and necessary function of adequately reporting the news. In the cases of necessity, perhaps it would have helped to accompany the briefs with other sources of information so the reader could retrieve it if he/she desired.

E. Coverage Criticisms

The previous analysis depicted some general trends noted in coverage from the 50's through the 90's. Various criticisms of the coverage at large will now be explored and substantiated with specific examples.

1. Journalists

Appendix 3 provides a comprehensive list showing the number of journalists at the *St. Petersburg Times* who wrote a story on red tide, the number of articles each wrote, and the total number of red tide-related articles written in each year analyzed. Appendix 4 provides an alphabetical listing of the journalists, along with the date and number of articles written by each one. One simple conclusion that emerges from an analyses of these data is that the reporters assigned to cover the red tide issue for the *St. Petersburg Times* changed often – sometimes daily.

Generally speaking, it seems apparent that the red tide issue was not a part of an assigned science beat. If it were, one might expect to see fewer journalists per given year in Appendices 3 and 4. Granted, some years were more consistent than others were. For example, John Gardner and Dick Morgan wrote a significant number of articles in the late 1950's, and James Lewis wrote many of the red tide articles in the 1960's (1963-1966). (Note: Many articles in the 50's and 1960's did not carry a byline, a standard journalistic tradition at the time). Pat Hiatte was a name that continually emerged in coverage of the 1971 red tide; Beirne Keefer covered the story sporadically in 1987, 1988, and 1989; and David Olinger dominated the coverage primarily in 1996 when about 150 manatees died from red tide-related causes. However, while these journalists racked up a significant number of red tide-related bylines, to say they consistently covered the story borders on being an inaccurate generalization. In 1971, for example, there were 76 articles written between 14 different journalists. In 1987, 18 articles were written between 7 different journalists, and in 1995, 24 journalists wrote a total of 41 articles. While it is difficult to statistically quantify these figures because of the many factors involved at various levels of the journalistic decision-making process, they provide support for the notion that the *St. Petersburg Times* assigned a number of different reporters to cover the story.

Constantly changing the journalist responsible to cover the red tide story can result in inconsistent reporting. On the other hand, assigning one reporter would likely improve the continuity of coverage. Given the scientific complexities surrounding the red tide phenomena, it becomes the duty of the journalist to consistently and diligently research the story as fully as possible in order to provide the public necessary contextual information. An added challenge is that red tides are not new to Florida. As phenomena that are documented as far back as the 1500's, they have become an inherent part of what it means to live in Florida. Nevertheless, when a red tide develops, the newspaper is responsible for tracking its progress on a daily basis. How long it will last, who will be affected, and how severe it is in relation to past red tides are issues that often go unanswered until well after the event has ended; it is up to the journalist (and his/her editor) to decide how to best cover the event on a daily basis as accurately as possible.

2. Choosing the Correct Words

Another challenge inherent to science reporting in general, but particularly relevant to red tide coverage, is finding a balance in a story between accuracy and intrigue. The journalist is challenged to explain the red tide event, with all of the entanglements of the science behind it, in language that is clear, accurate and interesting at the same time. The point is that it becomes increasingly difficult to stave off repetition and hackneyed language because it is a complex story that often demands daily coverage.

As mentioned earlier, Appendix 2 provides a comprehensive listing of descriptions of the red tide phenomena used by various journalists at the *St. Petersburg Times* from 1953 to 1997. What follows is an abbreviated listing of four general critiques on certain descriptive phrases pulled from the appendix that are ideal for a discussion on choosing the right words. The categories are not exhaustive or exclusive, and many examples are accompanied by a brief explanation in parentheses about why they are less than ideal.

1. Colorful, dramatic language that inaccurately portrays the phenomena in a science fiction-like, potentially alarmist manner; without enough context, the descriptions border on the brink of inaccuracy.

- 10/11/59: "the tiny marine race of 'terrible whip-tails' began to grow"

- 6/4/63: "the fish-killing scourge"

- 6/26/63: "Gymnodinium Breve, the microorganism which creates Red Tide when it bands together by the billions" (concentrations well below "the billions" of cells/l are considered a red tide)

- 7/18/64: "the dreaded, fish-killing Red Tide"; "...reproduction of billions upon billions of the tiny creatures. This kills fish by the millions."

- 9/1/64: "Gymnodinium Brevis is a trigger-happy little creature inhabiting coastal waters who goes on a reproductive rampage every now and then. And when he does, the result of his population explosion is a Red Tide." (The causative organism does not increase its reproductive rate during red tides; the high cell numbers result from a host of other biological and physical factors)

• 2/11/66: "The spread of the Jim Brevis organisms lays waste acres of fish, fouls the air and cripples resort communities until the plague disappears."

• 9/5/74: "The Red Tide has once again showed it is no respecter of the works of man and nature. Its victim this time is the experimental fishing reef off Clearwater Beach."

• 10/2/76: "Red Tide, the mysterious fish-killing plague of the sea"

2. Colorful but scientifically inaccurate language that potentially skews perception of the reality of the phenomenon.

• 6/5/71: "Red Tide, the fish-killing wave of dead and dying marine organisms" (red tide is an algae bloom of living cells that eventually die; when in very high numbers, their effect could be to kill or otherwise harm certain marine organisms but red tide is the algae bloom, not the animals killed by it)

• 6/8/71: "the fish-killing blight of dead and dying marine organisms" (same as previous)

• 7/26/71: "Fish kills from Red Tide continued to linger in Tampa Bay Sunday and officials report indications that the deadly organism may break out soon again." (This was a lead sentence that sounds more like science fiction. A danger lurks behind leads in science stories that are tasty and colorful; an attractive lead is desirable but its taste and color must be balanced by scientific accuracy)

• 1/17/87: "In these concentrations it suffocates fish, sending their carcasses washing ashore." (makes *G. breve* sound like Jason from a *Friday the 13th* movie)

3. Blatantly alarmist from a public health standpoint.

• 7/14/71: "This is not true for shellfish, such as clams and oysters, which concentrate the toxin to such a level that it can be fatal to humans..." (No fatalities have *ever* been associated with a *G. breve* red tide)

• 4/7/75: "Scientists aren't sure why the organism, always present in Florida waters, suddenly blossoms in enormous numbers, giving the water a reddish cast, suffocating fish, causing noxious fumes that choke and gag humans." (It does not cause noxious fumes; if concentrated along the shoreline where waves tend to break, its brevetoxins could cause respiratory discomfort but to say it chokes and gags humans is an alarmist, inaccurate generalization)

4. Uses language that is too general; needs to be more specific to qualify as "accurate."

• 4/3/82: "In high concentrations the Red Tide organism can cause massive fish kills and serious eye and respiratory irritations in humans." (How serious? To an out-of-towner reading about red tide for the first time, this information could be misconstrued. The truth is that for most people, red tides cause watery eyes and a ticklish throat, and heading inside or wearing a simple bandana over the mouth and nose remedies the discomfort immediately.)

• 7/4/82: "...Red Tide, which is caused by a microscopic algae that becomes extremely toxic to fish when disturbed." (This wording is vague. Is the toxic algae disturbed, or the fish, and what does this really imply?)

• 7/26/71: "Fish kills from Red Tide continued to linger in Tampa Bay Sunday and officials report indications that the deadly organism may break out soon again." (This was a needlessly alarmist lead that borders on being inaccurate. The word "deadly" needs more of an explanation, and saying the organism "may break out soon again" makes it sound like a runaway Loch Ness monster from a science fiction flick rather than the natural phenomenon that it is).

• 6/7/84: "the lethal bloom" (Using the word "lethal" without context is needlessly alarmist to someone unfamiliar with what red tides are all about. No red tides in Florida have ever killed a human – they are considered lethal to certain fish above particular threshold concentrations, but this type of information was not addressed in the article from which the quote was retrieved).

It is evident from these examples that journalists should be very cautious about exercising poetic license when covering a red tide story; while it is desirable to have color in every story, the potential for inaccurate or otherwise skewed information exists.

3. Technicalities / grievances

The tension that often exists between scientists and journalists is often heightened by minor discrepancies in the newspaper that often become gnawing grievances for the scientific audience. Journalists covering science are faced with many challenges; they must boil down the technicalities that make scientists tick into broader generalizations that are easily digestible by a mass audience. However, mistakes that consistently show up in the newspaper undermine the credibility of the newspaper at large and aggravate scientists along the way.

These errors range from minor grievances such as a misspelling or missed capitalization to more blatant scientific inaccuracies such as calling a microalgal red tide organism an animal or a bacterium. Minor or blatant, a bottom line remains: done consistently, they challenge the competence of the journalist, editor, and newspaper. The potential effects are considerable. If the public starts questioning journalistic competence, the credibility of the newspaper erodes. Furthermore, errors reported consistently could lead to a misinformed public audience to whom the newspaper is doing a disservice rather than enhancing public understanding.

In the coverage analyzed in the *St. Petersburg Times*, inaccurate generalizations were often made. A scientist accustomed to reading scientific journals written for a specialized, technically oriented audience quickly grows frustrated when these inaccuracies show up repeatedly in the newspaper. Journalists need to generalize, but not to the point of inaccuracy. Given the need for a more scientifically literate society, steps could at least be taken in the right direction through consistently solid, accurate science reporting.

(Note: Many of the following grievances deal with the way in which the causative red tide organism was named; its scientific name was often reported inaccurately. Keep in mind, however, that an added challenge for the journalist in this case was to keep up with how the scientific name of the organism changed over time based upon its structural characteristics. It was first called *Gymnodinium brevis*, which was changed to *Gymnodinium breve*, then *Ptychodiscus brevis*, and finally back to *Gymnodinium breve*. Scientists should recognize that the typical reader is not concerned with the scientific name as much as s/he is with the red tide situation at hand and how it might affect his/her daily life. While this comment is not meant to excuse a journalist from making every effort to get the name right, it is meant to emphasize the point that scientists and journalists should work together to reach a common goal – an accurate report that adequately addresses the situation).

1. Calling *G. breve* an animal or zooplankton when it is a plant (with a few animal-like characteristics; and has chlorophyll, other plant pigments, and other plant-like characteristics) or a protist (in between plant and animal)

NOTE: *G. breve* does have characteristics of both animals and plants, so in some instances the early references to *G. breve* as an animal might reflect the confusion among scientists over whether *G. breve* was an animal or a plant. At the time of the earlier coverage, protists were not recognized as a separate group, so it could be argued that these descriptions, taken together, accurately reflect the scientific confusion over the classification of this species.

Examples:

- 10/10/59: "The microscopic marine animals paralyze fish."

- 10/11/59: "a tiny marine animal in the Gulf of Mexico"

- 10/13/59: "It is caused by rapid increases of tiny marine animals which are normally in Gulf of Mexico waters."

- 6/26/63: "And they know Gym B., as the organism is called, manufactures some of its food in the same manner plants do even though Gym B. is an animal, one celled but still an animal."

- 8/25/63: "the minute animal"

- 2/4/64: "...rapid growth of microscopic marine animals"

- 7/8/71: "...Gymnodinium breve, a one-celled animal unusual in that it has some characteristics of a plant"

- 9/19/95: "the toxin-bearing zooplankton"

2. Calling brevetoxins gases when, in fact, they are not. Or saying *G. breve* actively emits a neurotoxin when, in fact, it is an endotoxin so it is harbored within the cell. Or saying the toxin is caused by decomposition when, in fact, it is not.

Examples: 12/9/53; 8/25/63; 4/16/64; 6/16/71; 8/24/82; 6/7/87; 4/8/89; 4/26/89; 4/20/97

3. Blatant errors in the name or concept.

Examples:

• 7/3/71: "Red Tide is caused by an organism called *Gymnodinium breve*, a member of a family of dinoflagellates found in seawater throughout the world" (*G. breve* has a limited distribution and is primarily found in the Gulf of Mexico)

• 9/15/78: "*Gymnodinimu breve*" (This very well could have been a typographical error, many of which slip by copy editors given the rigors of newspaper deadlines.)

• 5/26/84: "Red Tide is always in the Gulf." (*G. breve* is always in the Gulf but not a red tide; many factors are necessary to work synergistically for a bloom to develop).

4. Using "gym breve," "Gym. breve," "Gymnodinium breve" (without italics) or "Gym B" instead of the more accurate "*Gymnodinium breve*"

Examples: 6/26/63; 11/14/64; 1/18/66; 6/8/71; 10/4/77; 9/5/78; 12/2/96

5. Using "Gymnodinium Brevis," "Gymnodinium Breve," "Gymnodinium brevis" (without italics), "gymnodinium brevis" or "gymnodinium breve" instead of the more accurate "*Gymnodinium breve*"

Examples: 12/6/53; 10/1/59; 3/19/63; 6/26/63; 9/1/64; 6/18/71; 7/2/71; 10/7/94

6. Using "ptychodiscus brevis" instead of the more accurate "*Ptychodiscus brevis*"

Examples: 6/24/80; 8/5/80

Many of the examples listed may strike one as trivial errors. When done consistently, however, especially when it is a simple error like misspelling the scientific name, it challenges the credibility of the reporting job. This adds tension to the traditionally strained relationship that often exists between scientists and journalists.

4. Lifted Quotes

As discussed earlier, every decade of coverage analyzed was characterized by a discernable set of popular descriptions for red tide. The descriptions generally improved with time, and the red tide issue was reported accurately and contextually. Many descriptions reported can be criticized for various reasons.

One interesting practice that emerged from the analysis is what will be called lifting quotes. Lifted quotes are descriptions that were used in earlier news stories verbatim, or nearly so, by journalists who covered the red tide story at a later date. This practice may seem like a well-intentioned effort in consistency but journalistic credibility is compromised when the precedent description used is slightly inaccurate or worse, completely erroneous. A journalist should recognize that a story can, and does, change with time – this includes descriptions that can be updated and/or revised. He or she should maintain an attitude of healthy skepticism throughout the reporting process to ensure that the fairest and most accurate report is provided.

Many who are unfamiliar with how science works assume that science is equivalent to fact. The word "science" generally conveys definitives – all that is objective, true, factual, and proven. However, science is epistemological – it builds upon prior work that is tested, peer reviewed, and re-tested. Nevertheless, examples of science correcting itself seem endless. Perhaps the most obvious is the fact that the greatest thinkers of the past once thought the earth was flat. In another example, marine scientists once thought that the ocean below about 600 meters was azoic, or devoid of life, so they largely ignored it. However, today scientists actively study deep areas such as hydrothermal vents that actually teem with various life forms. A bottom line emerges: Often what is known in science is only as good as the methods available to test it. Like any story, then, the story of science can and does change with time. Science always tries to move forward, but occasional speed bumps along the way are inevitable during its quest for consensus and truth. Therefore, a journalist who relies on clips for background information *without verifying it* is takes a tremendous risk.

Catch-all phrases such as "the fish killer," "the fish-killing plague," and "Jim Brevis" were descriptive phrases that were used repetitively throughout certain blocks of time, but they are not considered lifted quotes for the purposes of this discussion. Lifted quotes are more extensive than mere phrases or chunks of words. Consider this example. An article on June 4, 1963 described the red tide in the following manner: "So-called Red Tide actually is a concentration of a minute marine organism, Gymnodinium Brevis, which is always present in these waters to some degree, sometimes multiplies to astronomical proportions. It then becomes fatal to fish, and, carried by the wind and a rough sea, irritates the respiratory system of human beings." An article published on August 14, 1963 used the exact same description, word for word. The problem with this description is not that it is horribly inaccurate or erroneous; the problem lies in the fact that it is unmistakably a lifted description that would benefit from revision. It gives the gist of what red tide is, but it suffers from overgeneralization. For example, a rough sea is not a prerequisite for human respiratory irritation. Red tide does not necessarily kill all fish, and it does not affect every human, contrary to the implication of the description used. While it is true that copy editors are trained to cut words because of limited column-inch space, in the case of red tide, qualifier words are often necessary for an accurate report. For example, in the quote above, simple qualifiers such as "*especially* in rough seas" or "irritates the respiratory system of *some* human beings" would have rendered the report more accurate. Such simple changes often make a significant difference in the overall accuracy of the story.

How many times have journalists relied on prior published information to avoid spending the extra time to pursue accurate, up-to-date information? Journalists have long used the tradition of referencing clips in the newspaper's morgue. It is one thing to strive for consistency, but wholly relying on certain clips verbatim raises many caution flags. Given the newsroom realities of deadlines, limited space and even less time, to call this lazy journalism seems an unjustified overstatement. One of the primary goals of the daily newspaper is to get breaking information out quickly, and journalists often do not have the time necessary to exhaustively pursue the best information. This raises the point that it is absolutely critical that the scientist(s) involved in the news story provides the most accurate information possible to the media to avoid a worst case scenario of inaccurate, lifted quotes. The basic point remains that journalists must be held accountable for their diligence or lack thereof in striving for accuracy, but the scientific sources involved must also recognize their active role in shaping the news content.

In another example on June 5, 1971, part of the verbiage used to explain the red tide phenomena was the following: "when the organisms die and decompose, they give off a toxin that affects the gill movements of many fish and cause them to drown." An article published on June 8, three days later, used the exact same phraseology: "When the organisms die and decompose, they give off a toxin that affects the gill movements of many fish and cause them to drown." Neither of these articles carried a byline so it is unclear if the same journalist wrote both articles. The description seemed to set a precedent for later articles, and therein lies the problem. An article published ten days later on June 18, 1971 reported, "Red tide is caused by rapid multiplication, death and decay of microscopic organisms called Gymnodinium breve." In terms of scientific accuracy, the latter statement missed the mark. (First, it is now known that *G. breve* does *not* reproduce more rapidly in red tides - its growth rate does not accelerate). Too much emphasis is placed on the death and decay of *G. breve* as an inherent part of red tides. While their eventual decline is a part of their natural life cycles and constitutes part of the final bloom stage (stages: initiation, maintenance, *termination/dissipation*), saying red tide is *caused by* rapid multiplication, death and decay of *G. breve* is inaccurate. The wording itself is vague; red tides do not necessarily signify rapid multiplication, rapid death and rapid decay as the description implies. Here again, technicalities are distilled, but accuracy was lost in the process.

Still another example of journalists relying too heavily on precedent descriptions was evident in three consecutive articles from 1978: September 5, 6, and 7. The following was reported in the first article, compiled from AP and staff reports: "Called Gymnodinium breve, the organism multiplies and 'blooms,' giving off a toxic rust-colored substance that paralyzes the fishes' gills." This description was reported verbatim in the articles on September 6 and 7. To someone unfamiliar with the science behind red tides, the description would seem to suffice. However, danger often lurks behind facts that are not checked and double-checked. The description suggests that *G. breve* is analogous to a squid, giving off a colored substance in a defensive response. However, *G. breve* does not "give off" a rust-colored substance; red tides may appear reddish because of the massive concentrations of cells but they have also been known to appear yellow, green, and brown. It is incorrect to make a direct link between the color of the tide and

G. breve's toxin. Furthermore, the *G. breve* cell contains a toxin that is released into the water if the cell is lysed by wind and waves or if the organism dies for other reasons. The description above wrongfully suggests that the toxin is continually released as the cells grow in a bloom situation. A bottom line emerges from this analysis: Accountability is one of the pillars of journalism, and it is irresponsible to rely on text from yesterday's newspaper.

A final example of lifted quotes was evident in four articles reported in 1989: March 28, March 30, April 4, and April 8. Because these descriptions are lengthy, the similarities are underlined so it is easier to recognize the quote-lifting trend.

- March 28 (By Joshua L. Weinstein; overall, a good article): "Red Tide is caused by tiny, poison-emitting plankton that are harmless - in fact, essential to the food chain - in small amounts. But sometimes, for reasons scientists don't understand, the amount of organisms in the water suddenly increases by phenomenal amounts."

- March 30 (News brief; no byline): "Red Tide is caused by poison-emitting plankton that are harmless in small amounts. Sometimes the amount of plankton in the water increases tremendously, causing a correspondingly high increase in the amount of poison. ... The plankton have a small amount of red pigment, and in large numbers can make water appear red."

- April 4 (By Joshua L. Weinstein and Mike Jackson): "Red Tide is a natural phenomenon caused by microscopic plankton that always are in the water. The plankton emit small amounts of poison and are harmless in their usual low numbers. For some reason, the number of plankton in the water occasionally swells to huge amounts. The large amount of plankton give off a correspondingly high amount of poison, killing finfish and rendering shellfish unfit for humans to eat. The plankton have small amounts of red pigment in them, but in huge numbers, appear as a mass of red water."

- April 8 (By Rick Bragg): "The plankton emit small amounts of poison and are harmless in their usual low numbers. For some reason, the number of plankton in the water occasionally swells to huge amounts and gives the water a faint reddish-brown tint. The concentration of plankton gives off a correspondingly large amount of poison, killing fish and rendering shellfish unfit for people to eat."

The primary danger of the repetition in these cases lies in the blanket generalizations that leach accuracy in each report. In the journalistic effort to provide a basic understanding of the red tide phenomena and how it works, scientific inaccuracies accrued. First of all, note that whereas "the fish killer" or "fish-killing organisms" seemed to dominate definitions in the early years of coverage (1950's and 1960's), "poison-emitting plankton" was the catchy phrase reported most often in the 1980's. As explained in the last example, *G. breve* does not actively "emit" a poison. Its "poison," a natural toxin called brevetoxin, is harbored within the *G. breve* cell. Upon cell rupture, as in wave breaks and wind sprays along the beach, the toxin can be released, but to make a blanket statement that *G. breve* "emits" a poison is erroneous (Pierce *et al.* 1989). What could emerge in the mind of a general public audience is an image of a small marine critter that paralyzes fish by shooting it with poison as a snake might do on land. In an effort to say as much as possible in as few words as possible, journalists often use catchy descriptors such as "poison-emitting plankton" instead of "plankton that have a poison that ...," for example, but great caution should be exercised so accuracy is not sacrificed.

Still another criticism regarding the repetition of a weak definition is the blanket treatment of how shellfish are implicated in red tide blooms. In the last two cases discussed (April 4 and 8, 1989), it is reported that the plankton "kill finfish and render shellfish unfit for humans to eat." This statement is problematic on two main fronts. First, while all fish are potentially susceptible to the effects of red tides, not *all* finfish are *always* wiped out by red tides as their statement suggests. In many cases, the bottom fishes such as grunts and groupers are most affected, but to make a blanket statement about all finfish is alarmist. Secondly, the reports fail to place the effect of red tides on shellfish into reasonable context. For example, they fail to explain that shellfish include oysters, clams, and coquinas but not crustaceans such as crabs and lobsters. Is it safe to assume that most readers could readily make this distinction? Indeed making blanket statements about "rendering shellfish unfit for humans to eat" has the potential to trigger an halo effect (discussed earlier) in which inadequate reporting negatively impacts the seafood industry at large rather than those seafood types that are specifically affected by red tides. It creates a scare among members of the general public and embeds a hesitancy to buy any seafood because of the fear of getting sick.

Journalists/editors often disdain qualifications and clutter in their descriptions because they are limited in the number of column inches they get for the story. However, qualifications are often necessary for clarification, especially in the case of a complex science story such as red tide. This is an inherently difficult conflict with which to contend because the reality of the journalist's job is that he/she does not have final say over the product that will appear in the newspaper the next morning. Perhaps this difficult reality signals a need for the copy editors (who often determine the final copy) to better understand the complexities of science stories by discussing them with the journalist so that essential details and qualifications are not mistakenly cut out.

In summary, implicit in a competent journalist is the astuteness to exercise caution when looking to precedent stories for information. Technicalities should be distilled, but not to the point of sacrificing accuracy or content. The newspaper is indeed the first draft of history; but one must not forget that drafts are constantly revised and improved. In short, using lifted quotes without assuring their accuracy is a problem.

Journalists are not the only ones who need to exercise caution in this regard. An equally significant point is the need for primary information sources such as the Florida Department of Environmental Protection to issue consistent, accurate information. Every effort should be made to clarify information for and with the journalist writing the story. Although it tends to go against the grain of traditional journalistic ideals of independence and autonomy, a simple check by the journalist to confirm the accuracy of his or her scientific descriptions with the scientist or investigating agency would not be unreasonable. It is understood that time is a major limiting factor for journalists, but the attempt should at least be acknowledged and intended. Maintaining accuracy and consistently would benefit both parties involved, and ultimately the public audience that reads and relies upon the information would be better served.

5. Use of Photographs

"A picture tells a thousand words" is a cliché that holds true in the newspaper business. Besides their marketing or layout appeal, photographs accompany many stories dealing with red tides to help the public better understand red tides. It is imperative that journalists exercise responsible news judgment not only in the words they write, but also in the photographs they choose. Similar to headlines, photographs often serve to summarize a particular news story, and they hold tremendous power in shaping public perception of the story at hand. If they are inaccurate or otherwise unacceptable, the public perception of the story could be skewed. For example, as reported in an article on June 28, 1980, Bill Nelson, president of Nelson's Seafood and Produce Inc. in Clearwater said, "There's been a difference since all this (Red Tide) stuff came out in the paper." His sales were down about one-third. "After people see pictures of dead fish piling up on the beaches and hear about how humans can absorb Red Tide contaminants, they kinda back off (on buying seafood) for awhile." This is part of the halo effect described in the previous section, and it lends credence to the power of pictures.

Many other articles that focused on public reactions to red tide events included the seemingly widespread opinion that the photographs printed in the newspaper were exacerbating the economic halo effect. Therefore, it was expected when analyzing about 500 red tide-related articles for this paper that many photographs would have been easy to criticize. However, that was generally *not* the case in the *St. Petersburg Times*. Most of the photographs analyzed were accompanied by responsible captions that clearly explained where the photograph of dead fish, for example, was taken, even down to the street address. For example, a caption on August 7, 1980 explained that the photograph was taken near 100th Avenue and Gulf Boulevard on Treasure Island. The *Times* also included maps to depict areas affected by red tide, although these were arguably too few and far between (10/4/77; 9/1/78: maps with briefs were occasionally included; 9/5/78: map showing where shellfishing ban is imposed; 1/24/80, 1/27/80, 6/13/80).

The most popular picture used in news reports was that of dead fish; there was not much diversity in terms of the subjects photographed for red tide articles. Rarely were pictures of the *G. breve* cell used, for example, which could have fostered an understanding of what red tide is all about by showing the cause rather than just the effect (dead fish). Overall, however, the *Times* more or less acted responsibly when it came to its choice and treatment of photographs to accompany red tide stories, but a few exceptions are worth noting. One exception was a photograph of a sanitation worker cleaning up dead fish (July 2, 1971). The problem was not the picture but the caption, which did not explain where the picture was taken. Assuming a tourist, for example, who does not know the area or understand the red tide phenomena very well sees such a picture, wouldn't he/she be likely to avoid heading to any Florida beach? This in effect could create a halo effect for many businesses in beach areas that in reality may not have been experiencing the effects of the red tide. Pictures are powerful journalistic tools that need to be handled responsibly.

Another example of poor use of a photograph occurred in an article printed June 25, 1984. It was an enlarged picture of a dead porcupine fish on the beach. The caption read, "Dead fish from Red Tide were probably more plentiful than people on Pinellas beaches this weekend." Similar to the last case, anyone who saw this picture and read the caption would likely steer clear of *all* Pinellas beaches when it may have only been a more or less localized area that was actually affected by the red tide. The caption was inadequate and even irresponsible. The picture, caption and headline ("Red Tide, wind, clouds conspire to make first summer weekend a beach bust") would probably be enough to convince any tourist or potential beachgoer to steer clear of the beaches.

An Associated Press article on March 22, 1996 about using satellites to study red tides was accompanied by a one-year-old *Times* file photo of dead fish killed in Sarasota. Again, including this type of photograph is dangerous because many people may just look at the picture and not read the explanation in the text. Would the public perception of Sarasota beaches in general be skewed? The possibility exists.

As mentioned earlier, public opinions blaming the media for the halo effect were reported in many of the articles analyzed, but the blame included broadcast reports as well as the print media reports. For example, an article printed August 1, 1971 reported, "Motel owners' wrath is vented mostly on NBC News, and AP reports which they feel sensationalized the Red Tide. Several mentioned newscaster Liz Trotta's nationwide TV broadcast saying the Red Tide was littering the entire gulf coast from Fort Myers north

150 miles with smelly fish." Another article on April 7, 1975 reported, "We ought to remember the disastrous results of a network television newscast about Red Tide along west coast beaches a few years ago. The Red Tide lasted less than a week, and then the beaches were clean. Clean and empty because cancellations from vacationers continued for several weeks. It wasn't national news when the Red Tide ended."

The risk of sensationalizing or skewing the news rises sharply when photos or footage are not adequately or accurately explained. Photographs stick in the mind of the reader – even if just a few were poorly used or explained, the impact could be substantial. The point is that the power of a photograph should not be underestimated. Choosing which pictures to use and how to describe them in a caption requires careful, responsible, fair and objective news judgment.

6. Science Fiction (or otherwise questionable) Headlines

Today's fast-paced society is inundated with information and choices on where to get it. Nevertheless it seems safe to assume that many people only have time to skim the headlines and look at the pictures. Therefore, headlines should not just catch the eye of the reader; they must be accurate and fair. Headlines are analogous to photographs in many ways. They stick in the mind of the reader and leave impressions about the stories they accompany. Similar to photographs, the consequences of inaccurate headlines could be significant. In a journalism ethics handbook, Black *et al.* (1995) provide accuracy and fairness checklists as reminders for journalists to exercise responsible news judgment. Two of the questions listed were the following: 1) Do your headlines (or broadcast promos or teases) accurately present the facts and context of the story to which they are referring?, and 2) Are the headlines and teases warranted by the text of the stories?

An analysis of the headlines used by the *St. Petersburg Times* for red tide stories revealed that the headlines often fell short of the journalistic ideals of accuracy and fairness. Many headlines were misleading, alarmist, or otherwise vague. It is important to recognize that very often the headlines are written by a copy editor on the newspaper staff, *not* by the reporter who writes the story. Nevertheless journalists covering science issues such as red tide events must be responsible enough to communicate with the copy editors and everyone involved so accuracy is maintained. After all, the public relies upon the headlines for an accurate teaser of the story.

Following is a list of examples of headlines that can be criticized in terms of their journalistic appeal. Coverage analyzed from the 1950's to the 1990's revealed that the headlines generally improved with time. Most of the problematic headlines were evident in the 1950's through the 1970's. The criticisms are grouped into six categories.

1. Blanket statements regarding the location of a red tide.

The effect of these headlines is analogous to that of photographs – essentially "worth a thousand words." The problem is that many times, the words suggested by the headline are inaccurate or otherwise misleading. In terms of red tides, it is always better to be as specific as possible regarding which beaches are affected by the outbreak. Otherwise, tourists and resident beachgoers avoid *all* beaches when in fact, this does not have to be the case. As discussed earlier, beach-front business and restaurant owners claimed they lost business because of poor media coverage of various red tide events.

- 9/28/57 "Red Tide Outbreak at Beaches"
- 10/2/57 "Red Tide Spreads in Suncoast Area"
- 10/3/59 "Suncoast Red Tide Increases"
- 10/17/59 "More Red Tide Killed Fish Seen in Gulf"
- 4/24/63 "Dead Fish Found on Gulf Beaches"
- 7/11/71 "Tide Effect Lingers on South Suncoast"
- 7/13/71 "Dead Fish Hit Gulf Beaches"
- 10/4/77 "Red Tide Strikes Florida's West Coast"
- 9/14/78 "Red Tide is still murder for fish on South Suncoast"
- 8/11/80 "Red Tide lingers in gulf" (Brief)
- 6/23/84 "Red Tide washes hundreds of dead fish onto shores"
- 9/15/85 "Red Tide Threatens Suncoast"
- 11/5/85 "Red Tide remains strong on coast"
- 6/14/87 "Red Tide remains unchecked in Gulf"
- 9/30/94 "Red Tide lingers off the Suncoast" (Brief)
- 7/24/95 "Red Tide is still nuisance at beach"

2. Headlines that assume too much.

These headlines attract the attention of readers, but can also be misleading. It is best to avoid gee whiz, breakthrough words that border on the brink of sensationalism.

- 10/8/57 "Solution Seen Soon in Red Tide Outbreaks" (There is no "solution" to red tides)
- 9/4/64 "Iron Said Red Tide Cause" (Iron may be a factor in red tides, but it is far from the only cause)
- 7/2/71 "Let's Search For Red Tide Cure" (The use of the word "cure" is a judgment call)

3. Sensationalist headlines that sound more like science fiction than accurate science reporting.

- 11/30/57 "Fish Killing Tide Swoops Into Bay, Mullet Hard Hit" (Red tides do not swoop into the bay like birds as this headline conveys)
- 10/2/59 "Red Tide Cuts Deadly Swath in Gulf Waters"
- 2/28/64 "Red Tide Researchers Looking For A Mysterious Something" (Too vague)
- 9/1/64 "Bugs' Sex Life Probed – Officials to hear Red Tide Study Report" (Classic sensationalism)
- 7/1/71 "'A Blood Bath' In Tampa Bay; Is Gulf Next?"
- 8/8/71 "Of Death, Life and Predators"
- 10/6/77 "The Crimson Killer"
- 9/14/78 "Red Tide is still murder for fish on South Suncoast"
- 9/27/78 "Red Tide – Poisonous Sea Creatures Menace Suncoast"
- 5/22/94 "Killer algae devastates fish along the East Coast"

4. Series of headlines (close to each other in terms of date published) that are inconsistent and therefore confusing to the reader.

- 6/5/71 "Suncoast Red Tide Confirmed – Shellfishing Banned
- 6/8/71 "Red Tide Called No Threat Now"
- 6/12/71 "Possible Red Tide Stops Shellfishing"

5. Generally alarming
    - 4/8/89 "Airborne Red Tide causes coughing epidemic"
    - 4/13/89 "Red Tide poisons tourist industry"

6. Headlines that show signs of improvement.

The following headlines are unusual in that they refer to positive aspects of the red tide event. These did not show up until the late 80's and 90's; they reflect an overall improvement in the coverage at large, as red tides were understood as natural phenomena rather than a science-fiction story. The headline analysis generally showed that most of what was reported about red tides was the bad news – that it began, and what effects it was having. It was not until the 80's and 90's that reports of red tides subsiding and/or beaches clearing were evident.

- 3/26/89 "Red Tide doesn't deter beachgoers"
- 4/13/89 "Red Tide hasn't slowed action near Sarasota" (fishing report)
- 5/5/89 "Coastal waters free of Red Tide" (Brief)
- 9/23/94 "Red Tide drifts; beaches are open"

7. Questionable Sources

The following questions from the accuracy checklist provided by Black *et al.* (1995) pertain directly to the issue of sources: Do you have a high level of confidence about the facts in your story and the sources that are providing them? If not, can you tell your story in a more accurate manner? If you have any doubts about your sources, can you delete them or replace them and achieve a higher likelihood or reliability? The analysis of red tide coverage by the *St. Petersburg Times* (1950's to 1990's) raised concerns about the sources used for scientific information, especially in the 1970's. While it seems unlikely that the journalists who used the questionable sources did so intentionally, using them may reflect an underlying lack of understanding about the red tide issue they were reporting. Following is a general discussion about the types of sources used in the decades analyzed. (*Note: This analysis assumes that the quotes reported were accurate.*)

Most of the articles written in the 1950's and 1960's quoted official sources such as the chief of the US Fish & Wildlife Service, the head of the Florida Board of Conservation marine laboratory at Bayboro Harbor in St. Petersburg, Florida, various marine biologists, the County Health Director, and spokespeople from the state labs. While it is true that not all official sources give accurate information, this did not seem to be a problem in the earlier coverage analyzed.

The 1970's, however, hallmark a time of transition regarding the use of sources. The year 1971 was also a particularly severe red tide year that received overwhelming press coverage nationwide. The traditional official sources were quoted, but so were members of the general public such as local fishermen and tourists in order to provide feedback on the red tide event. This becomes cause for concern when the public reactions quoted actually perpetuate a misunderstanding of the red tide issue at large. For example, an article printed on July 7, 1971 quoted a city public works administrator as saying, "The tide's intensity may be the reason for its beginning to kill game fish, which it hasn't been doing. Once it starts killing the bigger fish, our removal problem will have gotten much worse. ... Unless conditions change, those fish by the Skyway may wash up on the Gulf beaches, and there's a good chance that the tide itself will spread to the beaches," he said. While it would be reasonable and responsible to quote Dove regarding how much the city has spent cleaning up fish, for example, it was irresponsible to rely upon his speculative statements regarding the science behind the red tide phenomena. His reliability as a source of scientific information was highly questionable and had the potential to skew public understanding of the event.

Another example is from an article on September 5, 1978. A Florida Marine Patrol Sgt. Reportedly said in reference to the red tide phenomena, "It usually happens in the summer when it's warm. ... It doesn't happen too frequently. Many theories have been put forth, and over the years all the theories have been proven wrong." He also said copper sulfide treatments had been tried in the past, but apparently had no effect on the Red Tide. Unfortunately, these remarks were completely erroneous. Red tides typically occur in the late summer and early fall but they have occurred in all months of the year, and most experts consider them frequent events in Florida. Also, McLaughlin's statements about disproven theories was vague, and copper sulfide did kill red tide on a short-term basis – among other problems with its use, it also killed everything else around it, was expensive and impractical, but McLaughlin's information was too scant to paint an accurate picture. In this case then, McLaughlin's information was questionable.

In the 1980's, new sources of information popped up in the coverage. For example, the spokesperson for the Department of Natural Resources (DNR) in St. Petersburg, Florida was often quoted (the spokesperson was Violet Stewart throughout most of the decade), as was the director of Mote Marine Lab in Sarasota, Florida. In general, the sources were accountable and reliable in terms of the information they presented. Furthermore, one similarity between the 80's and 90's was that both decades featured a wealth of human-interest type stories about red tide, so plenty of unofficial sources such as tourists and beachgoers were also interviewed.

A dedicated, aggressive journalist is one who talks to the people and solicits reactions from nontraditional sources in addition to the traditional sources. After all, relying strictly on official sources often fails to tell the whole story, and official or standard sources of information are not always reliable. However, when it comes to science reporting in general and red tide reporting in particular, using unofficial sources for information other than reactions, opinions, personal experience or relevance to the story at hand raises a caution flag if those quotes are not verified or substantiated with reliable information

In a story that appeared on June 27, 1980, the owner of the Indian Rocks Seafood and Fish Company was quoted as saying that westerly winds from the gulf were blowing in "gas" released by the Red Tide organisms. "It's affecting people like a heavy smog," he said. He also said the choking stench from the Red Tide "bacteria" and the dying fish was nauseating, but "if you stay inside a bar or someplace where it's air conditioned you'll be all right." It is highly questionable that a restaurant owner should be quoted as saying something quasi-scientific about the red tide in the first place. What is worse is that the information he provided was wrong (outside of the last part about air-conditioning), and it probably skewed public perception of the event. First, *G. breve* does not release a "gas"; the owner was most likely referring to the effects of the organism's neurotoxin that causes respiratory problems when it gets aerosolized in the seaspray along the shore (which causes the fragile *G. breve* cell to rupture, and therefore the toxin is released). *G. breve* is particulate, not gaseous. It is also blatantly inaccurate to say red tide is a bacterium. This still seems to be a common misperception in the minds of the public. The organism responsible for red tide is a type of microalgae – bacteria may be associated with blooms, but the organism itself is not a bacterium. In this case then, the decision to quote the restaurant owner in this manner was either a mark of poor news judgment or a sign that the journalist did not understand enough about red tides to recognize that Fredericksen was an inappropriate source regarding the science behind them.

Aside from the aforementioned examples, there were also plenty of good sources used throughout reports in the 1980's. For example, instead of merely focusing on the negative aspects of red tides, many quotes pertained to the fact that red tide does not bother everybody in the same way; it is not like a plague that ruins the day, week, month, or more for everyone in Florida, as many media reports conveyed throughout coverage in prior decades. There were more qualifications in the descriptions used, which generally improved the accuracy of the information conveyed. There was also an effort to quote sources such as local doctors about the health effects of red tides; this information is invaluable to people wanting and needing to know how they potentially could be affected by a red tide, and what to do about it.

Coverage in the 1990's continually improved. Quotes from a variety of sources were used that generally complemented a balanced news report. If quotes from tourists and other unofficial sources were used, they were followed or preceded by quotes from a research biologist or more credible scientific source to verify the statements and to provide context. More of an objective balance was achieved in stories analyzed from the 90's that rendered them more responsible.

8. Good Examples

The discussion thus far has pointed out the inadequacies in the coverage of red tides by the *St. Petersburg Times* from 1953 to 1997. It would be remiss not to mention at least a couple of the articles that stood out from the rest because they were done *well.*

The first example appeared on July 8, 1971. It was a four-article spread, three of which carried bylines. The journalists were James Ryan, Patrick Hiatte and Roger Downey. Each of them had written multiple stories on red tide, and their basic working knowledge of the phenomenon came through in their reporting. Under the main heading of "Red Tide," the article headlines were the following: "Bay Area Toxicity Stronger," "Sarasota Economy Hit," "Phosphorus and Nitrogen Feed *G. Breve*," and "A Plague Since 1844." As suggested by the headlines, many newsworthy angles were explored in the articles that offered the reader an abundance of information and an accurate picture of the red tide story. The event was placed in context, described by appropriate sources, and not sensationalized. Furthermore, instead of a trite picture of more dead fish, the series highlighted a sketch of a *G. breve* cell that accurately portrayed the organism for the reader. Unfortunately, this type of photograph was only used about three times throughout the 44 years of coverage tracked.

Another example of a good article appeared on September 17, 1978. It was written by Jeff Klinkenberg. The headline was "Red Tide can be killed – but at a risk, experts say." Klinkenberg wrote a story that was accurate, full of context, and intriguing. He clearly took the time (or was granted the time) to do his homework. His narrative style made it a good read too – one with context, and one with qualified explanations. For example, instead of making a blanket statement such as, "Red Tide kills fish, marine animals and some birds, and causes respiratory distress in humans walking along the beaches," Klinkenberg wrote the following:

Although Red Tides are a natural, recurring phenomena, some are far worse than others. A bad Red Tide, like the one that affected Suncoast waters in 1946 and 1947, kills thousands of fish, marine animals and some birds. It also devastates reefs and may even sicken human beings who breathe in a toxin mist when waves break against the shore or boat.

He discussed economic and recreational impacts, and explained that not all fish are affected in the same way; some are more susceptible to the red tide toxins than others.

Klinkenberg also managed to keep the natural event in perspective while using colorful language at the same time. For example, he wrote, "The villain is called *Gymnodinium breve*, a one-celled plant-like organism so small that 25,000 of them are required to make an inch." The latter part of this sentence is a mark of a competent journalist – one who distills technical topics into understandable language familiar to the reader. In this case, calling *G. breve* a "villain" was not sensationalist because Klinkenberg qualified it in his descriptions. Many of the articles criticized thus far failed to provide such qualifications for the descriptors they used. Finally, Klinkenberg provided a helpful picture of the *G. breve* cell along with labels of the cell parts.

F. Recommendations for Improving Coverage

It is evident that the coverage of red tide events can be improved on many fronts. While the stories have generally improved with time, the historical analysis exposed weaknesses that can be ameliorated. Ideally a science reporter would be the one assigned to the red tide beat when it occurs, but that is not to say that another reporter could not do a comparable job; it takes a responsible, competent, dedicated journalist to cover any story well.

There is no doubt that red tides are a challenging issue to cover. There is still a lot to be learned within the scientific arena as to what role red tides play in the ecosystem and exactly how they come about. Many scientists researching red tides are hesitant to say too much to a journalist interviewing them because as Richard Pierce, director of research at the Mote Marine Laboratory in Sarasota, said, "Just when we think we know what red tide is doing, it throws us a curve" (Olinger 1996). This in itself presents the journalist with a challenge because he/she is not going to receive the bottom line types of statements often cherished in the journalism profession. Another challenge of red tides is the fact that they often require continual, daily coverage until they end. No one can predict when a red tide event will end so it becomes the challenge of the journalist to come up with different ways to portray the event and report with accuracy and context. Perhaps it is also true that many people only care about red tides when they kill fish or dolphins and manatees, and even make some humans sick. The truth of the matter is, however, that red tides can occur in all months of the year – they are a part of what it means to live in Florida and it is imperative that the public understands what they are all about. The potential outcomes of consistently inadequate coverage of the event are significant.

It would be remiss not to recognize the practical constraints inherent in the business of journalism. These include time, newspaper space, competing news stories, and budgetary issues. However, it would also be wrong not to acknowledge the fact that there is always room for improvement. Following are portions of the accuracy and fairness checklists discussed by Black *et al.* (1995) that are directly relevant to this discussion. It is followed by additional checklist points developed from this analysis that would benefit journalists assigned to the red tide story. Its primary goal is to help journalists live up to the principles of accuracy and responsibility. These ideals constitute the pillars of their craft – they must remain strong so the credibility of their profession at large is upheld.

<u>Accuracy checklist</u> (Black *et al.* 1995)

• Do you have a high level of confidence about the facts in your story and the sources that are providing them? If not, can you tell your story in a more accurate manner? If you have any doubts about your sources, can you delete them or replace them and achieve a higher likelihood of reliability?

• Have you double-checked the key facts?

• Are you highly confident that all the factual statements in your story reflect the truth?

• Have you used potentially objectionable language or pictures in your story? Is there a compelling reason for using such information? Would the story be less accurate if that language or picture were eliminated?

• Do your headlines (or broadcast promos or teases) accurately present the facts and context of the story to which they are referring?

<u>Fairness checklist</u> (Black *et al.* 1995)

• Is the meaning distorted by over- or under-emphasis?

- Are facts and quotations in proper context?
- Are the headlines and teases warranted by the text of the stories?

Other reminders or key points that are specific to red tide coverage

• It is better to assume your readers do not know much about red tides than to assume that they do. Provide as much explanation/context as possible.

• Being accurate in journalism means more than just getting the facts right - it means discussing them in the proper context and/or referring the reader to additional sources of information. Be wary of relying on descriptions from earlier stories. If you're going to use words like "lethal" and "deadly," explain them and put them in context!

• Avoid blanket statements. Be specific about what effects have been noticed so far, who may be affected, and which areas are or could be affected.

• Provide maps, specific locations of the bloom when possible.

• Accompany briefs with specific maps and references to other available information when possible.

• Write accurate, non-alarmist headlines.

• Write accurate, specific captions to accompany photographs.

• Use credible sources. Do not get lured by the desire for more color for your story and use quotes that just sound good. Exercise sound judgment in the sources you seek and the quotes you use.

• Provide context and recognize that red tides are natural phenomena that are a part of what it means to live in Florida (like hurricanes). Avoid being alarmist. Avoid sounding like a science fiction novel instead of a science news report.

• Make sure the science is correct. Consider checking with official sources such as state red tide biologists before filing the story. This does not mean sacrificing journalistic independence; it means ensuring accuracy and credibility.

• Make contacts at the agency governing the red tide science investigation (for example, Florida Department of Environmental Protection in St. Petersburg, Florida). Ensure that these sources are reliable, credible, and not alarmist.

• Report the end of a red tide bloom! (Reports that the red tide is gone are rarely found, but they should be).

G. Information Sources

Improving the communication between scientists and journalists would undoubtedly improve coverage of events such as red tides. Because red tides often require persistent inquiry as to their whereabouts, effects on public health and the economy and more, it might be useful to establish more web-based information sources into which journalists can readily tap to retrieve information. These web sites should be updated regularly to ensure that the most current and accurate information is provided. Care must be taken to omit inaccurate information and poor web sites; after all, not all web-based information is accurate.

There are many advantages to a web-based system. For example, the journalist has easy access to historical information on red tides and can concentrate on other aspects of red tides when speaking directly with the investigating scientist(s). Using the web would be a time-saver in this regard. This system might also help the investigating agency by decreasing the number of incoming phone calls and regulating the outgoing information in a more consistent and accurate manner.

Among the useful sites on Florida red tides that already exist are the following:
http://www.start1.com/

http://www.marinelab.sarasota.fl.us
http://www.redtide.whoi.edu/hab/
http://www.fmri.usf.edu/redtide.htm

CONCLUSIONS AND RECOMMENDATIONS

A. The Scientific Perspective

The story of Florida red tides – and our knowledge about them – is patchy. This patchiness makes the story of Florida red tides both fascinating and frustrating. Because of their effects on the marine environment as well as those on human health and the economy, red tides stand at a crossroad of concern in both the scientific and public mindset.

The comprehensive literature analysis and evaluation revealed many questions that red tide researchers have been asking for nearly 50 years. Among them are the following. How do blooms start? What defines a bloom or a patch? Does *G. breve* have a cyst stage? What is the significance of other spatially and temporally related bloom species? What factors contribute to the toxicity of a bloom? How do nutrient levels change before, during, and after blooms? How does *G. breve* achieve near monospecificity in a bloom situation? How do the physical factors at work in the Gulf of Mexico contribute to the occurrence of blooms? How do blooms terminate? It is not difficult to develop an extensive list of questions that still need answers. In short, while scientists have begun to unravel some of the mysteries of red tides, a number of gaps remain. As discussed throughout this paper, going back through the early literature and tracing the advancements that have been made can be a frustrating, confusing experience. Some of the early literature is either no longer applicable, easy to misinterpret, and/or occasionally contradictory.

One reason so many questions have lingered is likely a practical one: insufficient funding. The questions listed above necessitate long-term studies and interdisciplinary approaches; the reality is that they cannot be adequately addressed without sufficient funds. Today's funding game is especially competitive, and a frustrating one considering the basic questions such as those listed above that have gone without answers for decades. Fortunately, recently funded efforts such as ECOHAB: Florida (NOAA and EPA; http://www.fmri.usf.edu/ecohab) and special appropriations from the Florida legislature will address some of these fundamental ecological questions from a physical-biological approach to better understand the dynamics at work in red tide blooms. These questions become critical to answer considering the flurry of discussion in recent years regarding possible red tide control measures. Without understanding the fundamental dynamics of how red tides work and what their ecological significance is within the Florida Gulf of Mexico coastal ecosystem, addressing control measures seems premature.

Some answers to long-asked questions may be found if red tide data are re-evaluated with a fresh approach. It was evident in the comprehensive analysis that not only have many of the same questions been asked for years, but the same approaches to the data have been employed. The time seems ripe for a new outlook. As discussed earlier, one possibility lies in the principles of chaos theory and fractals. Red tides have proven themselves to be nonlinear systems that defy simple analyses and act as pulse-stability mechanisms for the Gulf coast ecosystem at large. Chaos theory, a branch of nonlinear dynamics, may hold potential for future red tide research. Among the possibilities is obtaining a fractal dimension for red tides by comparing perimeter and area data; ultimately, having a fractal dimension could help researchers better define a bloom or a patch in mathematical terms. Approaching questions with an entirely new perspective can be a daunting experience, but also one with many potential rewards.

B. The Journalism / Public Information Perspective

The journalistic analysis presented in this paper is based largely on one newspaper; more analyses with other newspapers would be necessary to qualify the analysis as representative of the media in general. Nevertheless significant conclusions can be drawn. As shown in the second half of this paper, the portrayal of red tides in the news media has often been one of a science fiction drama rather than a natural science phenomenon. The bottom line that journalists often seek to report is that much like hurricanes, red tides are a natural part of what it means to live in Florida; however, it seems safe to say that most members of the public are only aware of the negative effects of red tides (dead fish in waterways, for example) and the news they read about is usually the bad news of red tides. It is critical that those assigned to cover the story familiarize themselves with the science behind red tides and understand that they are a natural phenomenon occupying a functional niche within the Gulf coast ecosystem. Otherwise, the story that finds itself in the newspaper is often inadequate; at worst it could be inaccurate and ultimately skew the public perception of the reality of the red tide phenomenon.

One former Outdoor Editor for the *St. Petersburg Times* wrote the following in an article on August 8, 1964: "When the outbreaks of Red Tide hit Florida on occasion, it always seems to the citizens here that this state is getting an overdose of bad publicity. Motel owners and those engaged in the tourist trade feel that the news media play the story to the hilt, almost with a vengeance." Although this quote was written in the 1960's, it is likely that it still applies to today's public mindset. It is evident from the critical analysis of coverage in the *St. Petersburg Times* between 1953 and 1997 that there is room for improvement in the way the media handle the red tide story. Accuracy and intrigue constitute the lifeblood of a good science news story but this was often not the case in the coverage analyzed. Inaccuracies ranged from repetitive misspellings, erroneous red tide descriptions, and lack of context, to irresponsible headlines and alarmist, poorly explained photographs that could ultimately cast a negative eye on the state of Florida at large. After all, the messages portrayed in the media have the potential to reach and affect a wide readership in many different ways. Compounding their impact is the fact that most members of the general public rely solely on the mass media for their information about science (Steinke 1995).

However, it is wrong for citizens to cast a net of blame solely at the newspapers; the media have a responsibility to cover the issue consistently and accurately. Contrary to the idea portrayed in the quote listed above, a truly objective media organization would not approach a story or play a story "with a vengeance." It is easy to blame the messenger (that is, the media) when a seemingly negative event occurs, especially if coverage of the event is deemed inadequate by scientists and/or the public. At the same time, however, it is necessary to examine the role of *all* participants in the communication line involved in the final output of the red tide story: scientists, journalists and the public.

At the heart of this discussion, therefore, is a simple concept: communication. This discussion of red tides has pointed a spotlight on the idea of effective communication, both within the scientific community and in the realm of the public. The communication link between scientists and the public is generally mediated by journalists. The responsibility of effective communication of science information to the public, however, is not restricted to the journalist nor is it incumbent solely on the scientist. Rather, both parties need to place more effort into understanding each other's role and function in the communication process, and both need to work at improving it. In today's atmosphere of increasing public distrust regarding the media and arguably science as well, the idea of improving this communication link assumes tremendous significance.

As discussed earlier, an underlying tension has always existed between scientists and journalists. The irony is that the ultimate goal of both parties is accurate communication of science information. Relatively simple steps could be taken by both parties to ensure that the communication of information to the public is accurate and provided in context. The recommendation checklist for journalists provided in the previous chapter would not only benefit journalists but the scientists involved in the story as well. A simple effort by journalists and scientists to understand each other's functions and goals would undoubtedly help in the overall effort to improve science communication at large. Many possibilities for improved coverage also exist in newly emerging web-based information sources available. Given its relatively quick, user-friendly retrieval, web-based information holds a great deal of promise in terms of improving consistency and accuracy in the flow of information between scientists, journalists and the public.

Funding opportunities tend to increase for issues deemed critical in the public eye, and emphasizes the significance of an improved science communication process to science in general. It is important to improve the communication link because doing so benefits all parties involved. Theoretically, scientists could obtain answers to the vexing questions they have asked for years; journalists would fulfill their responsibility to provide accurate, contextual science information and ensure the credibility of a significant institution that currently lacks it; and the public would become more scientifically literate and therefore better able to tackle public policy issues related to science. As phenomena that are poorly understood by scientists who have been studying them for years, red tides will always be challenging for the journalists assigned to cover them. Red tides and the scientific debates enveloping them are dynamic; as long as accuracy and intrigue are maintained, the news story of red tides could and should be equally as energized and attract just as much attention in the public eye.

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APPENDIX I. THE PROS AND CONS OF SELECTED REVIEWS INVOLVING *G. BREVE*

1. An Annotated Bibliography of Red Tides Occurring in the Marine Waters of Florida
   By: Robert F. Hutton
   Date: 1956
   Pro: Historical information
   Con: Outdated; Not specific to *G. breve* (discusses *Ceratium, Gonyaulax, Rhizosolenia*)

2. Red-Tide Research Summarized to 1964 including an Annotated Bibliography
   By: George A. Rounsefell and Walter R. Nelson
   Date: 1966
   Pro: Focus on *G. breve*; accurate physiological information; comprehensive
   Con: Relatively outdated

3. Florida Red Tides - Educational Series No. 17
   By: Karen A. Steidinger and Edwin A. Joyce
   Date: 1973
   Pro: Well-documented; Offers some ecological ideas/concepts; Fairly comprehensive
   Con: Relatively outdated; Few hard data included

4. Phytoplankton Ecology: A Conceptual Review based on Eastern Gulf of Mexico Research
   By: Karen A. Steidinger
   Date: 1973
   Pro: Fairly comprehensive; Written for a more general audience
   Con: Not specific to *G. breve*; Written same year as previous (not much new information)

5. Basic Factors Influencing Red Tides
   By: Karen A. Steidinger
   Date: 1975
   Pro: 1st article to outline stages of bloom development; 1st to discuss importance of life cycles; 1st to show initiation of blooms offshore
   Con: Now outdated, but set the stage for much of today's research

6. Biologic and Hydrographic Aspects of Red Tides
   By: Karen A. Steidinger and Ken Haddad
   Date: 1981
   Pro: Discusses information not presented in previous reviews (e.g. 1st to stress importance of physics/satellites)
   Con: No detailed physiological information about *G. breve*; Not comprehensive

7. Marine Dinoflagellate Blooms: Dynamics and Impacts
   By: Karen A. Steidinger and Gabriel A. Vargo

Date: 1988
Pro: Information on general bloom stages/dynamics
Con: Not specific to *G. breve*

8. Some Taxonomic and Biologic Aspects of Toxic Dinoflagellates
By: Karen A. Steidinger
Date: 1993
Pro: Comprehensive reference section about toxic dinoflagellates in general
Con: Not specific to *G. breve*

9. *Gymnodinium breve* Red Tide Blooms: Initiation, Transport and Consequences of Surface Circulation
By: Patricia A. Tester and Karen A. Steidinger
Date: 1997
Pro: Significant information on the role of physics/current systems in *G. breve* blooms
Con: No discussion on broader ecological significance

10. Bloom Dynamics and Physiology of *Gymnodinium breve*
By: Karen A. Steidinger, Gabriel A. Vargo, Patricia A. Tester, Carmelo R. Tomas
Date: 1997
Pro: Relatively comprehensive summary; Specific to *G. breve*
Con: Not much information on biochemistry of brevetoxins or ecology

APPENDIX 2. RED TIDE DESCRIPTIONS FROM 1953-1997 (*ST. PETERSBURG TIMES)*

1953

Date	Descriptions
12/6/53	"the plague which kills fish"; "the Tide"; "The Red Tide gets its name from a tiny marine organism called Gymnodinium Brevis which turns waters a muddy red and kills fish in the immediate area by poisoning them."
12/9/53	"The Red Tide is named because a large concentration of minute organisms pack so closely in the water that it appears to have a reddish hue. These organisms release an as yet unidentified poison in the water, killing fish."
12/11/53	No description

1957

Date	Descriptions
8/20/57	"a Jim Brevis outbreak"; "the population of Brevis"
9/7/57	No description
9/28/57	"the fish killer"; "Red Tide is caused by a microscopic form of marine life known as Gymnodinium brevis. It is present in Gulf waters all year in low numbers, and is part of the food chain in the sea. Occasionally certain conditions (wind, temp., water salinity, etc.) reach a stage which causes the organism to split and multiply in tremendous numbers, releasing a poison into the water which kills fish. The poison can be carried by tiny droplets of water to the beach, and may cause throat and nasal irritation."
9/29/57	No description
9/30/57	"the fish killer"; "the red tide organism, technically known as Gymnodinium brevis"
10/1/57	"the Red Tide micro-organism - a tiny marine pest known as gymnodinium brevis, which forms in huge numbers, and turns water a reddish brown, killing fish by poisoning them"
10/2/57	No description
10/3/57	"the Red Tide, the scourge that has menaced us for a decade"; "gymnodinium brevis - the microorganism which, when in abnormal quantities, can kill fish of most any species"; "Jim Brevis"
10/4/57	"a large patch of Red Tide organisms"
10/5/57	"It's a stinking situation, this Red Tide."
10/6/57	No description
10/7/57	"infested waters"
10/8/57	"the fish-killing organisms"; "the plague"; "Red Tide 'bugs'"
10/9/57	"the fish killer"
10/12/57	"the fish-killer"

10/13/57	"the Red Tide organism"
10/14/57	"Tide-stricken Gulf areas"; "the Red Tide organism"
10/16/57	"the Red Tide organism"
10/18/57	"No Tide was found in northwest channel..."(picture caption); "Looking for 'Jim Brevis'" (picture caption); "the micro-organism"; "the Tide"; "gymnodinium brevis"
10/21/57	"the fish-killing organism, gymnodinium brevis"
10/22/57	No description
10/25/57	No description
10/28/57	No description
10/30/57	"the Red Tide organism"
11/3/57	No description
11/6/57	"the fish killer"
11/7/57	No description
11/12/57	No description
11/23/57	No description
11/24/57	No description
11/25/57	No description
11/30/57	"Fish Killing Tide Swoops Into Bay, Mullet Hard Hit" (Headline); "Red Tide organisms"

1959

Date	Description
10/1/59	"fish-killing Red Tide"; "the fish-killing organism which forms the Red Tide"; "The microscopic organism - gymnodinium brevis - 'blooms' under certain sea conditions, scientists have discovered, and poisons fish."
10/2/59	"fish-killing Red Tide struck the Suncoast"; "The organism paralyzes the respiratory system of fish, causing them to 'suffocate' from lack of oxygen"; "Only known effect on humans discovered by scientists comes from the air-borne gas in Red Tide areas."
10/3/59	"Red Tide draws its name from the murky, reddish-brown color of syrup-thick water infected by fish-killing organisms called gymnodinium brevis."; "in periods of prolonged and heavy rains...the tiny organisms seem to reproduce at a startlingly fast rate, scientists report."
10/4/59	"Red Tide is caused by gymnodinium brevis, a micro-organism ever present in Gulf waters. In periods of sustained, heavy rainfall the tiny organisms multiply and form Red Tide patches."; "Gymnodinium brevis gives off a toxic substance that paralyzes the respiratory systems of fish. When vaporized by waves crashing on beaches, the poison can irritate the mucous membranes of humans."
10/5/59	"Red Tide is caused by a rapid reproduction of the micro-organism gymnodinium brevis. It is always present in Gulf waters but reproduces rapidly after a period of heavy rains."
10/6/59	"Red Tide slammed into Sanibel Island..."; "the fish-killing epidemic"
10/7/59	"fish-killing Red Tide"; "Organisms causing Red Tide exist in Gulf waters at all times.

	Certain conditions, such as continued and heavy rainfall, are believed to cause the organism to grow, or 'bloom,' rapidly. The organism paralyzes the nervous system of fish."
10/8/59	No description
10/9/59	"the fish-killing organism"; "Red Tide is caused by rapid growth of tiny organisms in Gulf of Mexico waters. It paralyzes fish, causing them to die from lack of oxygen. Only known harmful effect on human beings is from wind-borne droplets of water from Red Tide areas which cause irritation of eyes, nose and throat."
10/10/59	"the fish-killing marine organism"; "The Red Tide, which last hit the Suncoast in 1957, is named because of the reddish-brown color of water caused by the fish-killing marine organisms. The microscopic marine animals paralyze fish."
10/11/59	"the tiny marine race of 'terrible whip-tails' began to grow"; "a tiny marine animal in the Gulf of Mexico"; "the one-celled dinoflagellates"; "the animals, always present in Gulf waters, began to become more numerous than usual"
10/12/59	"the Red Tide menace"
10/13/59	"fish-killing Red Tide"; "Red Tide gets its name from the reddish-brown color of water in affected areas. It is caused by rapid increases of tiny marine animals which are normally in Gulf of Mexico waters. When they multiply heavily they cause paralysis to fish, killing them by attacking the nervous system."
10/14/59	"fish-killing Red Tide"; "Red Tide is caused by a marine micro-organism which multiplies under favorable conditions, turning the water a rusty red. The organisms secrete a toxic substance which paralyzes the respiratory systems of fish."
10/15/59	"Red Tide is caused by a marine micro-organism which tints Gulf waters a reddish-brown when it multiplies. The organisms secrete a poison fatal to fish."
10/16/59	No description
10/17/59	No description
10/18/59	"The tide is caused by marine organisms that multiply under favorable conditions, color the water red and kill fish by secreting a poison that paralyzes their respiratory organs."; "the fish killer"
10/20/59	"Red Tide is caused by a marine organism which multiplies under favorable conditions, tinting the water a rusty red. The organisms discharge a poison fatal to fish."
10/21/59	"the fish-killing plague called Red Tide"
10/23/59	"the fish-killing plague, Red Tide"
10/24/59	No description
10/25/59	"The tide, which was discovered October 1, is caused by tiny marine organisms which kill fish by secreting a poison."
10/26/59	No description
10/27/59	"The Red Tide, so named because of its reddish-brown color, is an organism which reaches lethal doses under certain conditions. It then paralyzes the breathing systems of fish. Cold weather is believed to reduce Red Tide concentrations."
10/28/59	Confused definition - confuses Gulf red tides with algal blooms in lakes

1960

Date	Description
3/29/60	"the fish-killing microscopic organism called Red Tide"

1962

Date	Description
9/26/62	"Red Tide is caused by a microscopic organism which discolors Gulf waters and paralyzes fish causing them to die."
9/27/62	"Red Tide is the name given to a conglomeration of a tiny organism which kills fish."
9/30/62	No description
10/4/62	"the organism"
10/18/62	"a fish-killing Red Tide"; "Red Tide is a microscopic fish-killing organism which multiplies rapidly under certain conditions to give waters a reddish or brown tinge."
10/20/62	"Fish-killing Red Tide"; "growth of the microscopic organism causing Red Tide"

1963

Date	Description
1/5/63	"fish-killing Red Tide"; "the fish-killing organism which periodically 'blooms' in the Gulf of Mexico"; "The substance got its name from reddish, discolored water in areas where the organism had reached fish killing strength."
1/10/63	No description
2/7/63	"The Red Tide is caused from a microorganism commonly known as 'jim brevis' which under certain conditions multiplies in the Gulf of Mexico and causes fish to die in large numbers."
3/1/63	"Red Tide is a sudden increase in a microscopic salt water organism periodically off Florida coasts. Such a mass of the organism kills fish apparently by affecting their ability to breathe."
3/5/63	No description
3/9/63	No description
3/10/63	No description
3/19/63	"a marine organism called gymnodinium brevis, which turns the water red. Always present in the Gulf to some extent, heavy concentrations kill fish and give off gases that are respiratory irritants to human beings."; "Scientists have determined there is a correlation between heavy rainfall and mushrooming of the Red Tide organism..."
4/3/63	No description
4/4/63	No description
4/5/63	"Red Tide, the reddish-brown fish-killing organism"
4/6/63	"The Red Tide organism (scientific name Gymnodinium Brevis) is a microscopic plant-like organism (phytoplankton) which drifts in the sea. They almost always are present, but it is only when they multiply in great numbers, turning the sea water a brownish-red, that he

	organism is able to kill fish."; "the notorious Red Tide" (picture caption)
4/7/63	No description
4/8/63	No description
4/9/63	No description
4/10/63	"the tiny Red Tide microorganism"
4/12/63	"Red Tide organisms are maintaining fish-killing strength in the area"; "the Red Tide organism - Gymnodinium brevis..."
4/13/63	No description
4/14/63	"the fish-killing plague"; "the fish-killing organism which discolors water with a reddish tinge"; "Strong sunlight is one of the factors scientists believe cause the rapid growth of fish-killing microorganisms"
4/15/63	"olfactory organism"; "a mysterious something"; "We've heard it called a micro-organism, phytoplankton, Gymnodinium brevis and Jim Brevis. It is all of these. Speaking in scientific terms the Red Tide is a mass of tiny organisms called Gymnodinium brevis. To avoid the tongue-twisting name the organism is often called Jim Brevis, and that's what we'll do too. Red Tide is a collective name for a massive concentration of Jim Brevis."
4/16/63	"the fish-killing micro-organism"
4/17/63	"Red Tide is the common name for reddened sea water caused by increased concentration of a tiny marine plankton poisonous to sea life."; "the red marine organisms"
4/18/63	"the fish-killing organism"
4/19/63	No description
4/20/63	No description
4/21/63	No description
4/24/63	No description
4/25/63	"the fish-killing marine organisms"; Gymnodinium breve
4/29/63	No description
5/1/63	No description
5/2/63	No description
5/3/63	No description
5/6/63	No description
5/7/63	No description
5/8/63	No description
5/16/63	"fish-killing Red Tide"
5/28/63	"the organism recently littered beaches..."
6/4/63	"Red Tide ... the fish-killing scourge"; "So-called Red Tide actually is a concentration of a minute marine organism, Gymnodinium Brevis, which, always present in these waters to some degree, sometimes multiplies to astronomical proportions. It then becomes fatal to fish, and, carried by the wind and a rough sea, irritates the respiratory system of human beings."
6/16/63	No description
6/26/63	"Gymnodinium Breve, the microorganism which creates Red Tide when it bands together

	by the billions"; "And they know Gym B., as the organism is called, manufactures some of its food in the same manner plants do even though Gym B. is an animal, one celled but still an animal."
7/7/63	No description
8/13/63	"the dreaded organism, which kills fish and tourism on Florida's West Coast"; "So-called Red Tide actually is a concentration of a minute marine organism, Gymnodinium Brevis, which, always present in these waters to some degree, sometimes multiplies to astronomical proportions. It then becomes fatal to fish, and, carried by the wind and a rough sea, irritates the respiratory system of human beings."
8/14/63	No description
8/17/63	No description
8/19/63	No description
8/20/63	"Red Tide is a water condition resulting from the sudden multiplying of microscopic plants to untold numbers, releasing poisons that kill fish."
8/21/63	"the fish-killing water condition"; "Red Tide results from a fantastic increase in numbers of a microscopic marine plant that blossoms within a day or two to fish-killing numbers. The dead fish drift ashore, keeping visitors away and forcing communities to send out cleanup crews."
8/24/63	No description
8/25/63	"the Red Tide organism - has been present in sufficient quantities to cause beach residents to cough and choke on several occasions"; "Red Tide organisms, he said, explaining that since the gas is only present when the minute animal is broken up, accurate counts of live organisms are impossible."
8/27/63	"Rusty-red waters, indicating the presence of full-blooming marine micro-organisms, poisonous to sea life..."
8/28/63	"the Red Tide organism - Gymnodinium breve - have been bothering beach residents in the area"; "The particles cause irritation and choking in the throat, watery eyes and coughing"
8/29/63	"the Red Tide organism Gymnodinium breve"
9/10/63	No description
9/12/63	No description
9/19/63	No description
9/20/63	"...Red Tide organisms, which kill sea life when in sufficient concentrations"
10/14/63	No description
12/5/63	"Red Tide, the unexplained explosion of marine micro-organisms which turns water a rusty red and sometimes kills sea life along the Florida West Coast"

1964

Date	Description
2/4/64	"Red Tide is the common name given to rusty red water caused by an unexplained and rapid growth of microscopic marine animals."; "Besides leaving millions of dead fish with a far-reaching odor in their wakes, Red Tide organisms near shore often emit a gas which

	causes human beings to cough."
2/5/64	No description
2/28/64	"the organism"; "the fish-killing blooms of Gymnodinium breve"
3/25/64	No description
4/16/64	"the Red Tide organism, Gymnodinium breve"; "the prodigious growths of the organism which lead to the fish-killing blooms"; "Red Tide is a concentration of at least 250,000 of the organisms in a quart of water. The organism...emits a neurotoxin which kills fish in great numbers."
4/30/64	No description
7/18/64	"the dread, fish-killing Red Tide"; "Red Tide is caused by Gymnodinium Brevis - sometimes called 'Jim Brevis' - which is a one-celled protozoan with animal and plant characteristics"; "...reproduction of billions upon billions of the tiny creatures. This kills fish by the millions."
8/7/64	"the fish-killing organism"
8/21/64	"The tide organism, when it hits, kills millions of fish."
8/28/64	"the plague"
9/1/64	"Gymnodinium Brevis is a trigger-happy little creature inhabiting coastal waters who goes on a reproductive rampage every now and then. And when he does, the result of his population explosion is a Red Tide."
9/4/64	No description
9/5/64	"Red Tide, a water condition resulting from the wild increase of a one-celled plant - Gymnodinium Brevis - found in all ocean waters."
9/15/64	No description
10/7/64	"Red Tide is caused by the rapid multiplication of a minute marine organism. It kills fish by the millions."
10/27/64	"Red Tide, a huge growth of minute marine organisms which kills fish by the millions, is a frequent visitor to the Suncoast. Little is known of the phenomenon, despite years of research."
10/29/64	"Red Tide is the name given to a huge growth of minute marine organisms called Gymnodinium breve. Under certain conditions, the organism multiplies fantastically, killing fish by the millions."
10/31/64	"The tides - scientifically, they are immense 'blooms' or concentrations of minute marine life - emit a toxic substance which kills fish by the millions and can poison oysters and other shellfish, making them toxic to humans."; "Most fish-killing red tides are caused by organisms which are related, or similar to Gymnodinium breve."
11/14/64	"the Red Tide organism - Gymnodinium breve..."

1965

Date	Description
5/23/65	"The tides are caused by a sudden population explosion among a tiny organism, so small that

	it is invisible except under a microscope. Present at all times in seawater, these organisms use up all the oxygen in the water when they reproduce so greatly that they color the water red, and this kills the fish."
7/22/65	"Millions of little creatures"; "the Red Tide organism, Gymnodinium breve"; "the fish-killing organism"; "the fish-killing tide"

1966

Date	Description
1/18/66	"Red Tide is caused by a fantastic multiplication of the minute organism, Gymnodinium breve, in the shallow coastal waters. When the organism reaches concentrations of 600,000 or more per quart of water it discolors the sea water, kills fish and emits a substance which makes humans cough and wheeze."; "the plantlike Red Tide organism"
2/11/66	"The spread of the Jim Brevis organisms lays waste acres of fish, fouls the air and cripples resort communities until the plague disappears."
3/31/66	"Red Tides are caused by a microscopic organism exhibiting both plant and animal characteristics. The organism was isolated in 1947 by a Miami scientist working on behalf of the State Board of Conservation and was named Gymnodinium breve."; "Scientists call it G. breve, or Jim Brevis for simplicity's sake."; "This condition discolors the water and emits a poisonous substance with paralyzes marine life and eventually kills it."
4/7/66	No description
7/8/66	"the fish-killing organism"; "Gymnodinium breve, the organism which causes Red Tide"
9/25/66	"this plague"; "Red Tide - known to those in the know as Gymnodinium breve - or G. breve"
10/28/66	"Red Tide, the mass of microscopic organisms that kill almost all marine life with which they come into contact, has been discovered in the Gulf of Mexico."; "the organism causing the Red Tide is a dinoflagellate called Gymnodinium breve, which has been responsible for extensive fish kills in the past."
10/29/66	"Gymnodinium breve, the organisms which cause a Red Tide..."
11/1/66	No description
11/9/66	"the Red Tide organism Gymnodinium breve"

1967 & 1968: No articles analyzed

1971

Date	Description
3/8/71	"the dreaded Red Tide"; "A Red Tide occurs when a tiny organism called Gymnodinium breve (G. breve) multiplies at a tremendously high rate in sea water. Billions of the microscopic animals discolor the water (thus the name) and kill most fish with which they come in contact by paralyzing their respiratory systems."

6/5/71	"Red Tide, the fish-killing wave of dead and dying marine organisms"; "when the organisms die and decompose, they give off a toxin that affects the gill movements of many fish and cause them to drown"
6/8/71	"the fish-killing blight of dead and dying marine organisms"; "Red Tide is the result of rapid multiplication of reddish colored, tiny organisms called Gymnodinium breve (G. breve. When the organisms die and decompose, they give off a toxin that affects the gill movements of many fish and cause them to drown"
6/12/71	"Red Tide is the result of the death and decay of tiny sea organisms. They give off a neuro-toxin that is fatal to many species of fish. The toxin becomes concentrated in shellfish."
6/15/71	"the red tide organism, a poison producer"
6/16/71	"Red Tide is the result of the death and decay of tiny marine organisms called dinoflagellates. The toxin produced by decomposition is fatal to many species of fish and can cause illness in humans. The symptoms of red tide poisoning are a tingling in the face and lips, lethargy and nausea."
6/17/71	No description
6/18/71	"Red tide is caused by rapid multiplication, death and decay of microscopic organisms called Gymnodinium breve."
6/19/71	"the cell-population explosion"
6/22/71	No description
6/29/71	"gymnodinium breve, the marine organism that kills fish when it reaches a heavy bloom. A heavy concentration of the organism turns the water red."
6/30/71	"The red tide is caused by the bloom of an organism always present in the water, but the thing triggering the bloom is unknown."
7/1/71	No description
7/2/71	"Fish-killing, smell-producing Red Tide organisms"; "Red Tide - scientific name, gymnodinium breve - is not indigenous to Florida or the Suncoast. The world knows about it and its cousins who kill fish..."
7/3/71	"Red Tide is caused by an organism called Gymnodinium breve, a member of a family of dinoflagellates found in seawater throughout the world." It multiplies rapidly when conditions of water temperature, salinity and nutrient levels reach a certain stage."
7/4/71	"Gymnodinium, the organism that causes red tide"
7/5/71	No description
7/6/71	"Gymnodinium, the organism causing the red tide"
7/7/71	"the organism"; "the Tide"
7/8/71	"the organism, which creates a neuro-toxin that paralyzes fish and other marine animals"; "a natural phenomenon"; "Red Tide is caused by a massive population explosion of Gymnodinium breve, a one-celled animal unusual in that it has some characteristics of a plant."

7/9/71	"Red Tide organisms which create a toxin that paralyzes sea creatures"
7/10/71	"Gymnodinium breve, the Red Tide organism"; "the fish-killing organism"
7/11/71	"the fish killer"
7/12/71	No description
7/13/71	No description
7/14/71	"Although Red Tide, a population explosion of microscopic organisms called Gymnodinium breve, kills fish and other marine animals, the fish are safe for humans to eat if they are caught before the Red Tide's toxin takes total effect."
7/15/71	"the neuro-toxin-producing micro-organisms"; "the tide"
7/16/71	"the Tampa Bay plague"
7/26/71	"the deadly organism"
7/27/71	"Deadly Red Tide"; "the Red Tide organism, Gymnodinium breve"
7/28/71	"the fish-killing microorganism Gymnodinium breve"
7/29/71	No description
7/30/71	"Gymnodinium breve, the Red Tide organism"
7/31/71	"As the Red Tide known as Gymnodinium breve continues its sweep here, it breeds another in its wake: a tide of red ink."
8/1/71	No description; "Gymnodinium breve (Red Tide)"; "the killer G. breve"; "the Red Tide siege"
8/2/71	"fish-killing Red Tide"; "the deadly micro-organism Gymnodinium breve which secretes a neurotoxin fatal to fish and other marine life"
8/3/71	"Gymnodinium breve, the Red Tide organism, was as toxic as ever..."; "the toxic organism"
8/4/71	"Gymnodinium breve (Red Tide)"
8/5/71	"G. breve"
8/6/71	"the fish killer"; "Gymnodinium breve (Red Tide)"
8/7/71	"G. breve"
8/8/71	"the Red Tide's murderous attack"
8/9/71	No description
8/10/71	No description
8/11/71	"a world of Red Tide"
8/12/71	"the fish-killing plague"
8/13/71	No description
8/14/71	"fish-killing Red Tide"; "the fish-killing phenomenon"
8/15/71	"Gymnodinium breve, the Red Tide organism"
8/17/71	"Gymnodinium breve, the Red Tide organism..."
8/18/71	"the fish-killing blooms of Gymnodinium breve, the Red Tide organism..."
8/19/71	"Red Tide producing organisms"
8/24/71	No description
9/1/71	"the Red Tide fish killer"

9/16/71	"the killer organism"; "sudden explosion of microscopic algae that give the water a rust color"
10/2/71	No description
11/9/71	"Red Tide is a natural disaster, like a flood or hurricane..."
11/17/71	No description

1972

Date	Description
10/18/72	"the tide, which periodically creates huge fish kills that wash ashore, stinking up our beaches and causing huge headlines in faraway newspapers that hurt tourism."; "Red Tide is one form of pollution that is not manmade, at least as far as we know."

1973

Date	Description
11/8/73	"An outbreak of the fish-killing Red Tide that has brought large numbers of scavenging sharks close to beaches is minor..."

1974

Date	Description
3/15/74	"It is an organism that is always present in Gulf waters. Sometimes it undergoes a population explosion and the number of organisms vastly increases. It kills fish beyond a certain concentration. It stinks."
3/25/74	No description
4/14/74	"Gymnodinium breve, the proper name for the microscopic plankton that recently killed thousands of tons of fish..."; "...the mystery of what awakens the organism from its normally dormant state"
9/5/74	"The Red Tide has once again showed it is no respecter of the works of man and nature. Its victim this time is the experimental fishing reef off Clearwater Beach."
10/16/74	No description
11/21/74	No description

1975

Date	Description
4/7/75	"Red Tide is a killer - it kills the tourist business along the coast; it kills fish and fishing..."; "the tiny Gymnodinium breve organism that causes Red Tide. Scientists aren't sure why the organism, always present in Florida waters, suddenly blossoms in enormous numbers, giving the water a reddish cast, suffocating fish, causing noxious fumes that choke and gag humans."

1976

Date	Description
4/22/76	No description
9/3/76	"A tiny, invisible marine plant with a huge price tag"; "The name is Gymnodinium breve, the red tide organism that periodically piles the Sunshine State's famed beaches with stinking white windrows of dead fish"
10/2/76	"Red Tide, the mysterious fish-killing plague of the sea"; "The unpredictable 'bloom' of the tiny marine organism, whose toxin causes fish to suffocate, is moving northward..."; "Researchers have been unable to explain what triggers the organism's growth, which usually lies dormant in the sea. Concentrations in excess of 250,000 cells per liter of sea water release enough toxin to kill fish."

1977

Date	Description
10/4/77	"the outbreak"; "a massive congregation of marine plankton called Gymnodinium breve"
10/5/71	"The term Red Tide is applied to massive congregations of a plant-animal organism called gymnodinium breve. Always present in the gulf, in large concentrations it gives off a toxin that kills fish by attacking their nervous and respiratory systems."
10/6/77	"the mysterious plankton scientifically known as *Gymnodinium breve* gathers for yet another assault on the state's marine life and, often in turn, Florida tourism"; "Marine life is slaughtered."
10/14/77	"Red Tide organisms"
11/11/77	"the mysterious toxin that discolors water and causes massive fish kills by depleting oxygen"; "the Red Tide organism"

1978

Date	Description
9/1/78	"Red Tide, an ancient but still mysterious scourge, occurs when microorganisms release poisonous byproducts into seawater."
9/5/78	"the fish-killing Red Tide"; "caused by a minute organism that is always in the water"; "Called Gymnodinium breve, the organism multiplies and 'blooms,' giving off a toxic rust-colored substance that paralyzes the fishes' gills."
9/6/78	"The Gymnodinium breve microorganisms"; the fish-killing organisms; "The mysterious Red Tide is caused by a tiny organism called Gymnodinium breve. The organism is always in the water, according to scientists; however, when it multiplies and 'blooms' it gives of a toxic rust-colored substance that paralyzes the fishes' gills."
9/7/78	"toxic organisms"; "Red Tide is caused by a tiny organism called Gymnodinium breve. Marine biologists say the organism is always in the water. However, when it multiplies and 'blooms' it gives of a toxic rust-colored substance that paralyzes the fishes' gills."; "the algae-born microorganisms"
9/8/78	"the toxic organisms"; "Red Tide, a killer of saltwater fish, also contaminates shellfish,

	which can absorb the toxin in the organisms and live"
9/9/78	No description
9/12/78	"the paralyzing Red Tide toxins"
9/13/78	No description
9/14/78	"...but they absorb the poisonous alkaloid toxins produced by the gymnodinium breve organisms, which can cause illness and even death if eaten."
9/15/78	"the Red Tide organisms, and the poisons they produce"
9/17/78	"The paralyzing poisons produced in a Red Tide outbreak suffocate swimming fish. Shellfish, such as clams and oysters, can survive a Red Tide outbreak, but their bodies absorb the toxins and can poison persons who eat them."; "The Stuff, the dreaded Red Tide"; "The villain is called Gymnodinium breve, a one-celled plant-like organism so small that 25,000 of them are required to make an inch."
9/23/78	"Red Tide organisms produce a poison that suffocates swimming fish. Some shellfish, such as clams and oysters, can survive but absorb the toxins into their bodies making the shellfish unfit to eat..."
9/27/78	"Poisonous sea creatures" (from headline); "the microscopic creatures"
10/21/78	No description
11/19/78	"the ocean phenomenon called Red Tide"; "the toxic Red Tide organism"; "an elusive mystery"; "A Red Tide occurs when a microscopic organism, Gymnodinium breve, 'blooms' and multiplies to concentrations reaching millions of cells per liter of water. The organism - biologists shorten the name to G. breve in their discussions - occurs naturally in the gulf in concentrations of less than a thousand per liter. G. breve is a toxic dinoflagellate (self-propelling cell), a thousandth of an inch in diameter, which in high concentration kills fishes, invertebrates, and sometimes sea birds."

1979: No articles analyzed

1980

Date	Description
1/24/80	"Called Gymnodinium breve, the Red Tide organism occurs naturally in sea water but occasionally 'blooms,' giving off a toxic rust-colored substance that paralyzes fish. Although shellfish can absorb the toxin, humans who eat the clams and oysters become nauseated and sometimes die."
1/27/80	No description
6/13/80	"fish-killing Red Tide"; "Red Tide is caused by the accumulation of large numbers of a tiny marine algae, Ptychodiscus brevis, formerly known as Gymnodinium breve. The organism normally occurs in the Gulf of Mexico in small numbers. It is not certain what causes the organism to multiply or 'bloom' and threaten marine life."
6/17/80	No description
6/18/80	No description
6/20/80	"Red Tide is caused by the concentration of a tiny marine organism that produces a fish-

	killing poison. The poison may build up in shellfish, such as oysters and clams. It doesn't harm the shellfish, but could cause illness in anyone who eats them."
6/21/80	"Red Tide is caused by the concentration of a tiny marine organism that produces a fish-killing poison."
6/24/80	"Red Tide is caused by the concentration of a single-celled organism - ptychodiscus brevis - that produces a fish-killing poison."
6/25/80	"Red Tide is a concentration of a tiny plant-like organisms called ptychodiscus brevis. In multitudes, the organisms color the water red and produce a neuro-toxin that paralyzes fish so they can't breathe."
6/26/80	No description
6/27/80	"Red Tide is the name given to a heavy concentration of tiny plant-like organisms called Ptychodiscus brevis. They emit a neuro-toxin that paralyzes fish so they can't breathe. Those organisms become airborne in rough seas and can cause respiratory irritations in humans."
6/28/80	"Red Tide is caused by large concentrations of a microscopic organism, which gives off a chemical that produces reddish-brown water and suffocates fish by clogging their gills."
7/11/80	"the tiny organism that frequently causes fish and shellfish problems along Florida's gulf coast"; "Red Tide is caused by a sudden, unexplained concentration of a microscopic organism that is naturally present in salt water. The tiny creatures produce a poison that suffocates sea animals and can irritate the eyes, nose and throat if inhaled."
8/1/80	"Red Tide, so called because it sometimes tints the water a reddish-brown, is caused by tiny marine algae called Ptychodiscus brevis. The algae's presence in the Gulf of Mexico is normal, but elevated concentrations can threaten marine life. Fish die when poison produced by the Red Tide organism interferes with their respiration."
8/5/80	"The microorganisms that cause Red Tide"; "The Red Tide organism ptychodiscus brevis produces a toxin that suffocates fish, contaminates shellfish and can irritate the human respiratory tract."
8/6/80	"single-celled Red Tide organisms and the toxin they produce when they proliferate. The toxin suffocates fish, contaminates shellfish and can irritate the human nose, eye and throat if inhaled in sea spray. Affected waters often are tinted reddish-brown, giving the Red Tide its name."
8/7/80	"Red Tide is caused by a single-celled organism that occurs naturally in sea water. Under the right conditions the organisms proliferate, turning the water reddish-brown and producing a toxin that kills fish, contaminates shellfish and can irritate the human eye, nose and throat."
8/8/80	No description; calls it "patchy"
8/11/80	"Like an invisible but troublesome ghost, the Red Tide lingering along the Suncoast scratched at the throats and noses of beach visitors this past weekend"; "Red Tide is a concentration of single-celled organisms that turn the water reddish-brown and produce poisons fatal to fish."
8/13/80	No description
8/23/80	"the poison produced by the organisms"

8/29/80	"poison-producing Red Tide organism"

1981: No articles analyzed

1982

Date	Description
4/3/82	"In high concentrations the Red Tide organism can cause massive fish kills and serious eye and respiratory irritations in humans."
4/22/82	"Red Tide, a single-celled microorganism producing a poison that attacks the nervous system of fish, is ingested by shellfish, and people who eat the infected shellfish can become seriously ill."
7/4/82	"...Red Tide, which is caused by a microscopic algae that becomes extremely toxic to fish when disturbed."
7/23/82	"Red Tide, a fish-killing algae that also accumulates in shellfish"; "Red Tide, made up of microscopic floating algae that appears reddish in color"; "the algae, which contains a toxic poison"
8/3/82	"the toxic microscopic algae"
8/13/82	"the reddish algae"; "Red Tide is caused by a toxic algae that not only kills fish but also builds up in bivalves, such as oysters and clams."
8/14/82	"the toxic reddish algae"
8/24/82	"Red Tide is a massive concentration of a marine organism called Ptychodiscus brevis. In huge blooms that turn the water a reddish color, it kills fish by emitting a poison that paralyzes their ability to breathe. It also causes respiratory discomfort in people."
12/21/82	"the deadly red tide organisms"

1983: No articles analyzed

1984

Date	Description
5/25/84	"The fish-killing Red Tide is composed of huge blooms of a marine organism called P. breve. At concentrations of more than 250,000 organisms per liter of water, the organisms can begin to kill fish by suffocation, according to Dr. Richard Pierce, acting director of Mote. If Red Tide reaches the surf and becomes airborne in breaking waves, it can cause respiratory discomfort in people. And a massive outbreak of the lethal tide can send thousands of dead fish to the beaches."; "...was a definite reddish color, she said. This is what gives Red Tide its name"
5/26/84	"the fish-killing marine organism"; "Red Tide is the name given to huge blooms of the tiny marine organism P. breve that suffocates fish. When the organism becomes airborne, which can happen as waves break along the beaches, it can cause respiratory discomfort in humans"; "Red Tide is always in the Gulf"

5/29/84	"P. breve cells, the marine organism that kills fish when concentrated in huge blooms. Red Tide can also cause respiratory discomfort in humans."
5/30/84	"the fish-killing micro-organisms"; "The microscopic P. breve algae that cause Red Tide are toxic to marine life when the concentration reaches 250,000 parts per liter."
5/31/84	"the microscopic P. breve organisms that cause the toxic tides"; "red tide algae"
6/7/84	"The fish-killing Red Tide..."; "the lethal bloom"; "the marine organism P. breve that in massive concentrations forms what is called Red Tide."; "P. breve becomes a respiratory irritant in people when the cells become airborne in breaking waves along the beaches. But one of its most obnoxious side effects is the thousands of smelly dead fish it sends to the beaches."; "P. breve, always present at least in small quantities in the Gulf..."
6/22/84	"The microscopic P. breve organisms that cause Red Tide generally are toxic to fish when there are 250,000 of them per liter of water"
6/23/84	"the mysterious, microscopic, oxygen-depleting P. breve organisms which cause fish to suffocate and tint the water red.";
6/25/84	No description

1985

Date	Description
9/13/85	"Red Tide, a patch of fish-killing algae that can deeply wound the fishing and tourism industries..."; "the reddish water"; "Paralyzed and strangled by the algae's poison, fish end up reeking on the beaches."
10/23/85	"the pesky microscopic algae"; "Airborne toxins from the algae can cause respiratory problems for humans. It also produces a toxin that paralyzes and eventually kills fish."
10/30/85	"Red Tide, a toxic algae that at worst can kill fish or irritate the throat and lungs of swimmers, has creeped north..."
11/2/85	No description
11/3/85	"Red Tide is toxic algae that can irritate the eyes, throat and lungs of swimmers and others at the beach. It also kills fish..."
11/4/85	No description
11/5/85	"the large bloom of toxic algae, which at its worst can cause respiratory problems for people, kill swimming fish and make shellfish unfit to eat..."
12/10/85	"the toxic algae"

1986: No articles analyzed

1987

Date	Description
1/1/87	"Red Tide is the name for outbreaks of huge concentrations of a tiny marine organism named P. breve. In these concentrations it suffocates fish, sending their carcasses washing ashore."
1/17/87	"Red Tide, the common name for high concentrations of a tiny marine organism, can

	accumulate in the flesh of shellfish, causing nausea in people who eat them."; "Red Tide is the name for outbreaks of huge concentrations of a tiny marine organism named P. breve. In these concentrations it suffocates fish, sending their carcasses washing ashore."
5/12/87	No description
5/15/87	No description
5/23/87	"Red Tide is the name for high concentrations of a tiny, common marine organism. It normally is harmless. But occasionally it multiplies rapidly into blooms that can spread across the Gulf for miles, giving the water a reddish tint and suffocating thousands of fish."
5/24/87	"Red Tide, a high concentration of marine organisms, contaminates shellfish."
5/26/87	No description
6/6/87	"Red Tide is caused by a common marine organism named P. breve. Harmless in normal concentrations, the tiny organism sometimes multiplies rapidly into blooms. In high concentrations, the organisms emit a poison that suffocates fish. The blooms get their name by the reddish tint they give to water."
6/7/87	"Red Tide is caused by a concentration of the organism P. breve. The organisms emits a poison that suffocates fish."
6/12/87	"the Gymnodinium breve (Red Tide)"
6/14/87	"Red Tide is caused by a high concentrations of the organism P. breve. The organism emits a poison that suffocates fish. It can irritate the noses, throats and eyes of beachgoers. But Red Tide is not considered dangerous to humans and there has been no ban on swimming at Pinellas County beaches."
7/15/87	No description
10/7/87	No description
11/4/87	No description
12/24/87	No description
12/27/87	No description
12/28/87	"a biological toxin associated with a type of Red Tide that occurs in waters around Canada and the northeast Atlantic coast."
12/29/87	No description

1988

Date	Description
4/21/88	"the 'red tides' of micro-organisms"
5/14/88	"microscopic algae began to reproduce quickly, thriving and exploding in a matter of days into a huge, toxic bloom"; "the same organism, Ptychodiscus brevis"; "toxic tides...damaging coastal economies as they choke marine life and foul beaches"; "phytoplankton, the microscopic plants that when multiplied billions of times create algal blooms"; "The term 'red tide' is used generically by scientists and others to describe any blooms, toxic or not, even though the algae that cause the tides can turn waters brown, yellow, green or other shades as well, depending on the makeup of the organism. Most algal blooms are not toxic to fish or people, even though the discolored and turbid waters

	can make swimming or fishing unpleasant."; "Ptychodiscus brevis - a single-celled, microscopic, plantlike organism that is just one of the many small, drifting plants and animals at the base of the marine food chain, known collectively as plankton. Ptychodiscus brevis causes Florida's Red Tide. ... Ptychodiscus brevis is one of 30 species that is toxic and affects the nervous systems of fish, causing death by suffocation."
8/23/88	"Gulf algae blooms"
10/5/88	"the one-celled organisms can kill fish and shellfish."
10/7/88	No description
10/19/88	No description
10/21/88	No description
11/6/88	"Red tides occur when algae become so populous the water appears red. In great concentrations they release toxins that are deadly to some marine life."

1989

Date	Description
2/2/89	"red tide" algae; "'Red tides' are dense clouds of red, toxin-producing one-celled creatures that are so concentrated as to stain the water red."
3/25/89	"the microscopic, plantlike organism kills fin fish with a toxin that attacks their nervous system"; "It does not kill shellfish, but it builds up in their systems, causing gastrointestinal illness in those who eat the shellfish."; "Red Tide is a natural phenomenon caused by dense concentrations of microscopic organisms called Ptychodiscus brevis"; "In high concentrations - known as 'blooms' - the organisms produce a poison that kills fish and may turn the water reddish brown, yellow or green."
3/26/89	"Red Tide, dense concentrations of an organism called Ptychodiscus brevis, produces a poison that can kill fish through their nervous systems."
3/28/89	"Red Tide is caused by tiny, poison-emitting plankton that are harmless - in fact, essential to the food chain - in small amounts. But sometimes, for reasons scientists don't understand, the amount of organisms in the water suddenly increases by phenomenal amounts. ... The huge amount of organisms in the water produces a correspondingly huge amount of poison, which paralyzes certain muscles inside fish. ... In Florida, it is caused by a sturdy plankton called Ptychodiscus brevis."
3/30/89	"Red Tide is caused by poison-emitting plankton that are harmless in small amounts. Sometimes the amount of plankton in the water increases tremendously, causing a correspondingly high increase in the amount of poison. ... The plankton have a small amount of red pigment, and in large numbers can make water appear red."
4/4/89	"Red Tide is a natural phenomenon caused by microscopic plankton that always are in the water. The plankton emit small amounts of poison and are harmless in their usual low numbers. For some reason, the number of plankton in the water occasionally swells to huge amounts. The large amount of plankton give off a correspondingly high amount of poison,

	killing finfish and rendering shellfish unfit for humans to eat. The plankton have small amounts of red pigment in them, but in huge numbers, appear as a mass of red water."
4/7/89	No description
4/8/89	"The plankton emit small amounts of poison and are harmless in their usual low numbers. For some reason, the number of plankton in the water occasionally swells to huge amounts and gives the water a faint reddish-brown tint. The concentration of plankton gives off a correspondingly large amount of poison, killing fish and rendering shellfish unfit for people to eat."
4/9/89	"Red Tide is a concentration of microscopic plankton that causes discomfort in several ways."
4/9/89	No description
4/10/89	"the phenomenon"
4/11/89	"The organisms that cause Red Tide are toxic to fin fish."; "Researchers don't know what causes millions of toxic organisms called Ptychodiscus brevis occasionally to bloom in coastal waters off Florida. The bloom turns the water a reddish-brown color, hence the name Red Tide."
4/12/89	"Red Tide makes people sick the same way it kills fish: from a poison that affects the nervous system. The poison is emitted by a plankton always in the water; but sometimes - for reasons scientists don't know - it fills the water in overwhelming amounts."
4/13/89	"Red Tide, named for the reddish-brown color the seawater can take on, is caused when toxic organisms bloom in coastal waters. The Red Tide kills fish and the microorganisms blows ashore to irritate humans."
4/14/89	"Red Tide is caused by a poison-emitting, microscopic plankton that always is in the water. Sometimes, though, the amount of plankton in the water increases to staggering amounts. The extra plankton give off extra poison, which kills fin fish and builds up in the livers of shellfish, making them poisonous to humans."; "Red Tide actually is a generic name for any condition in which huge amounts of poison-emitting plankton suddenly appear in the water."; "In Florida, a plankton called Ptychodiscus brevis causes Red Tide, but other plankton cause the fish-kills elsewhere."
4/15/89	"Besides irritating human respiratory systems, Red Tide can kill fish and birds."
4/16/89	No description
4/20/89	"Red Tide is caused when the amount of poison-emitting plankton in the water increases dramatically, giving off a correspondingly high amount of poison that kills fish."
4/26/89	"Red Tide is caused by a poison-emitting plankton that kills fish and makes shellfish poisonous to humans."
5/1/89	"Red Tide algae"
5/5/89	"Red Tide is caused by poisonous, microscopic plankton in the water. The plankton always is there, but sometimes, for reasons scientists don't understand, it increases to huge amounts. The poison, kills finfish and lodges in the livers of shellfish, making them toxic to humans."
5/12/89	No description

10/24/89	No description
10/26/89	No description

1994

Date	Description
9/20/94	"Red tide is an algae bloom with a cloudy, brownish-red color. Nobody knows what causes the blooms, but they know the effects: The algae suck up oxygen, which kills fish, and also emit airborne toxins that can cause problems for people."
9/20/94	"Red Tide is an algae bloom with a cloudy, brownish-red color. ... Nobody knows what causes the blooms, but they know the effects: The algae suck up oxygen, which kills fish, and also emit airborne toxins that smell bad and can cause health problems for people."
9/21/94	"Red Tide is an algae bloom with a cloudy, brownish-red color."
9/22/94	"Red Tide is essentially an algae bloom. It is caused by dense concentrations of microscopic organisms that release a toxin that irritates lungs and eyes and can be dangerous for people with respiratory problems. The algae blooms deplete oxygen in the water, killing fish."
9/23/94	"the fish-killing algae"
9/27/94	"Red Tide, an algae bloom with a cloudy, brownish-red color"
9/29/94	"fish-killing Red Tide"; "Red Tide, an algae bloom with a brownish-red color, usually forms in Florida waters in late summer."
9/30/94	"the algae bloom"
10/5/94	"Red Tide is caused by dense concentrations of microscopic organisms that release a toxin that irritates lungs and eyes and can be dangerous for people with respiratory problems. Red Tide algae blooms deplete oxygen in the water, killing fish."
10/7/94	"A microscopic organism, gymnodinium breve, turns water a brownish-red color and gives Red Tide its name. Dense concentrations, called blooms, are what trigger fish kills, but slight concentrations, which won't discolor the water, still can cause health problems in humans."
11/8/94	"Red Tide is caused by dense concentrations of microscopic organisms that release a toxin that irritates lungs and eyes and can be dangerous for people with respiratory problems. The toxin paralyzes fish and affects their membranes. The fish die of respiratory failure because they cannot process oxygen."
11/23/94	No description

1995

Date	Description
2/22/95	"a massive rusty algae bloom"; "Red Tide is formed by naturally occurring algae that make water look green to brownish red. The single-celled algae organisms emit a poison that attacks the nervous system of fish ..."
4/25/95	"the periodic enemy of fish and occasional irritant for coastal residents"; "the marine plankton bloom"; "Red Tide is caused by dense concentrations of microscopic organisms

	that release a toxin that irritates lungs and eyes and can be dangerous for people with respiratory problems."
4/28/95	No description
5/11/95	"the culprit"; "Red Tide, caused by dense concentrations of microscopic organisms that release a toxin, typically blooms in the fall..."
5/12/95	"occasional irritant of the sea"; "the Red Tide organism"
5/13/95	No description
5/14/95	"The algae that causes Red Tide, formed by dense concentrations of microscopic organisms that release a toxin, sucks oxygen from the water and kills fish."
5/16/95	"the algae bloom"; "Red Tide is caused by dense concentrations of microscopic organisms that release a toxin irritable to human lungs and eyes and dangerous for people with respiratory problems."
5/20/95	"the infested water"; "Red Tide, which depletes oxygen in the water and can kill fish, results from concentrations of microscopic organisms that release a toxin."
5/26/95	"Red Tide is a brownish-red algae bloom that usually hits Florida coasts in summer and fall. Microscopic organisms, brought together by an unknown combination of water temperature, sunlight and nutrients, release toxins and cause an outbreak."
5/27/95	"fish-killing algae"; "Red Tide is an algae bloom that typically hits Florida coasts in the summer and fall. It is made of microscopic organisms brought on by an unknown combination of water temperature, sunlight and nutrients."
5/30/95	"algae bloom"
6/2/95	"fish-killing algae bloom"
6/7/95	"A mysterious discoloration"; "a large algae bloom"
6/8/95	"Red Tide, the microscopic organism plaguing the Gulf Coast in recent weeks"; "the fish-killing algae"
6/13/95	"algae bloom"; "this miserable, naturally occurring phenomenon"; "It is caused by dense concentrations of microscopic organisms that deplete oxygen in the water and can kill fish."
6/14/95	"unpredictable algae bloom"; "Florida Red Tide, which carries the scientific name Gymnodinium breve, is an organism that is always present in the Gulf of Mexico. When it blooms, and scientists are unsure what triggers the reaction, the algae create a toxin that paralyzes fish so they cannot breathe, and they die."
6/15/95	"nagging Red Tide"; "huge offshore algae bloom"; "lingering Red Tide"
6/16/95	"microscopic organism that causes the algae bloom, gymnodinium breve, turns water a brownish-red color and gives Red Tide its name"
6/18/95	No description
6/21/95	No description
6/29/95	No description
7/13/95	"Red Tide consists of single-celled microscopic organisms that deplete the oxygen in the water, often causing fish to suffocate. Several species throughout the world can create the condition."

7/14/95	"an algae bloom"
7/24/95	"Like an unwanted house guest, Red Tide is sticking around."; "naturally occurring algae bloom"
8/1/95	No description
8/3/95	No description
8/4/95	No description
8/14/95	No description
8/26/95	No description
8/27/95	"Red Tide, the organism that depletes oxygen in the water and can kill fish"
8/29/95	"the algae bloom"
8/31/95	No description
9/1/95	"The single-celled microscopic organisms deplete the oxygen in the water, often causing fish to suffocate."
9/15/95	"marine bloom"; "the toxic algae bloom"; "the naturally occurring irritant"
9/19/95	"Red Tide, the toxin-bearing zooplankton that made gulf beaches a smelly mess."
9/20/95	"the fish-killing Red Tide"
10/17/95	No description
10/21/95	No description
12/4/95	No description

1996

Date	Description
2/7/96	"the microscopic organism"
2/24/96	"the naturally occurring phenomenon"
2/27/96	"the shellfish toxin commonly called red tide"
3/8/96	"algal blooms, or tides, are named after the color they turn the water"
3/15/96	"They tiny single-cell organism that creates the red tide contains a poison that attacks the nervous system of fish and other animals. In the case of manatees, the red tide toxin attacks the nerves that control breathing simply shutting them down and killing the animal."
3/16/96	"Red Tide, a toxic micro-organism that can kill fish"
3/17/96	No description
3/22/96	"phytoplanktons"; "Red Tides are caused by several species of marine phytoplankton, or microscopic plants, that produce potent chemical toxins."
3/23/96	No description
4/3/96	"Red Tide, a toxic organism that can kill fish, contaminate shellfish and cause respiratory problems for humans"
4/6/96	No description
4/9/96	"a toxic algae bloom that has been prevalent on the southwest Florida coast"
4/17/96	"Red Tide, which produces a toxin that can poison marine life"
4/19/96	"Any animal near a Red Tide outbreak could inhale its microorganism."

4/22/96	"the microscopic organism that causes Red Tide is well known; why it explodes into Red Tide remains a mystery."; "one of these dinoflagellates - Gymnodinium breve - that 'blooms' into toxic Red Tide."
4/23/96	"Red Tide, which causes muscle spasms and paralysis"
4/24/96	No description
4/28/96	"a natural marine toxin, Red Tide, is to blame..."; "the mysterious, oxygen-depleting toxin is the top suspect"
4/30/96	No description
5/4/96	"Red Tide, a kind of algae bloom that can be toxic to marine organisms..."
5/8/96	No description
5/12/96	"the algae bloom red tide"
5/14/96	"toxic microorganisms known as Red Tide"
5/15/96	"Red Tide - the phenomenon suspected of killing 155 manatees in southwest Florida this year - is relatively uncommon in waters of Citrus County. Typically, the bloom of toxic micro-organisms is found farther south on the gulf coast."
5/16/96	No description
5/18/96	"Red Tide, a bloom of toxic micro-organisms"
5/31/96	"Red Tide, a naturally occurring microorganism"; "Red Tide is caused by a growth of microscopic plantlike organisms. In dense concentrations they can cause seawater to look reddish-brown, kill fish and other marine life and cause respiratory irritations in people."
6/4/96	"Red Tide, a toxic microorganism"
6/6/96	"Red Tide contamination"; "the microscopic algae"
6/12/96	"Red Tide is a naturally occurring organism that can kill fish, contaminate shellfish and cause respiratory problems for humans. In dense concentrations, it can cause seawater to look reddish-brown."
7/3/96	"Red Tide is a kind of algae bloom that occurs periodically off the west coast of Florida. The tiny organisms release the brevetoxin, which suffocates the manatees by affecting the nervous system."
7/12/96	No description
7/19/96	No description
8/9/96	No description
8/18/96	"the toxic microorganism Red Tide"
9/8/96	"the little understood phenomenon of Red Tide"; "the algae"; "Red Tide is a naturally occurring organism that can be found in the Gulf of Mexico and in waters around the world. Dense concentrations can cause the seawater to look reddish-brown, kill fish and other marine life and cause respiratory irritations in people."
9/25/96	"The tide is actually a type of algae bloom that periodically occurs off the west coast of Florida"
9/27/96	"We recalled that the summer before, a Red Tide fouled our beaches and the town air because of a gel bloom in gills of fish as microscopic gymnodinium breve feeding on fecal water suffocated them."

10/5/96	No description
10/23/96	No description
12/2/96	"Red tides are natural events."; "Red Tides are caused by Gymnodinium breve, a single-cell organism that typically exists in low concentrations in the gulf but can erupt into blooms massive enough to color the sea a reddish brown. During these population explosions, the dying cells release a nerve poison that can kill fish and other marine life."

1997

Date	Description
1/4/97	"Red Tides are algae blooms. They occur annually in the Gulf of Mexico but rarely invade manatee wintering areas in deadly concentrations."
1/25/97	No description
2/24/97	"Red Tide is a natural phenomenon. In North American waters, it's caused by a single-celled algae that gives off a powerful toxin. The algae is always in the water, but at its normal concentrations it causes no problems. Occasionally, for reasons not fully understood, the organism undergoes a population explosion called a bloom and gives off enough toxin to cause massive fish kills."
3/14/97	No description
4/9/97	No description
4/13/97	"Algae blooms are natural phenomenon, but scientists do not completely understand what causes them. The blooms occur when different types of tiny algae that live in the Gulf of Mexico proliferate rapidly. The blooms can discolor the water, can be slick or gooey, and some types, such as Red Tide, can cause respiratory irritations and fish kills."
4/20/97	"Red Tide is a little-understood organism that blooms under certain conditions, giving off a powerful toxin that turns water a brownish-red and depletes oxygen, thus suffocating fish and causing respiratory problems in people. The algae are always in the water but cause no problems at normal concentrations."
5/16/97	No description
7/7/97	"Red Tide is caused by dense concentrations of microscopic organisms that suck up the oxygen from the water. ... These nasty little organisms also release a toxin that irritates lungs and eyes and can be dangerous for people with respiratory problems."

APPENDIX 3. *ST. PETERSBURG TIMES* JOURNALISTS WHO COVERED RED TIDE, 1953-1997

Year	Journalists; #	Total # Articles
1953	n/a	3
1957	Red Marston; 1 Dick Morgan; 6 Larry Holmgren; 1 Chuck Albury; 1	36
1959	John Gardner; 4	26
1960	n/a	2
1962	n/a	6
1963	Frank Bargen; 1 James Lewis; 8 Red Marston; 1 John Gardner; 1 Bill Hager; 1	62
1964	James Lewis; 3 Red Marston; 1	21
1965	James Lewis; 1	2
1966	James Lewis; 2	11
1971	Alan Cowan; 1 James Ryan; 7 Robert Fraser; 2 Pat Hiatte; 8 Roger Downey; 1 Carolyn Nolte; 2 Bob Kyle; 1 Robert Hooker; 4 M.P. Fleisher; 1 Jane Daugherty; 1 Red Marston; 2 Bob Bender; 2	76
1971 (cont.)	Judy Sedgeman; 1 Calvin Taylor; 1	
1975	Judy Sedgeman; 1	1
1977	Betty Kohlman; 2	4
1978	Jack Barrett; 1 Joe Hartmann; 4 Vanessa Williams; 3 Paul Tash; 5 Jeff Klinkenberg; 1 John Pennington; 1	17
1980	Tim Smart; 1 Helen Huntley; 2 Jonathan Susskind; 5 Theresa White; 1 Richard Koenig; 1 Deborah Blum; 1 Betty Kohlman; 2	25
1982	Barry Bradley; 1 Steven A. Marquez; 1 Craig Roberton; 1 Jodi Fleisig; 1 Betty Kohlman; 1	9
1984	Betty Kohlman; 5 Christopher Smart; 1 Ed Marks; 3 Vernon Smith, Jr.; 1	9
1985	Bob Port; 1 Rob Suskind; 1 Bill Moss; 1	8

Year	Journalists; #	Total # Articles
1987	Jeff Klinkenberg; 1	18
1987 (cont.)	Tom French; 1 Kathy Subko; 1 Betty Jean Miller; 1 Beirne Keefer; 3 Stevan Allen; 1 William Fox; 1	
1988	Beirne Keefer; 1 Dail Willis; 1 David Rogers; 1	8
1989	Beirne Keefer; 2 Chris Sherman; 1 Lisa Grace Lednicer; 1 Bill Moss; 1 Cesar Alvarez III; 1 Joshua Weinstein; 4 Alan Goldstein; 1 Wilma Norton; 1 Norma Wagner; 1 Karen Datko; 2 Sue Landry; 1 Rick Bragg; 1 Mark Journey; 1	28
1994	Laura Griffin; 1 Felicia Rosser; 1 Terry Tomalin; 1 Jerome Stockfish; 1 Monica Davey; 2 Tim Roche; 1 Marla Cone; 1	17
1995	Tim Roche; 4 Nancy Klingener; 1 Kit Troyer; 4 Peter Wallsten; 2 Warren Hart; 1 Ed Quioco; 2	41

Year	Journalists; #	Total # Articles
	Mike Jackson; 1 T. Christian Miller; 1 Jean Heller; 1	
	Mark Albright; 1 Amy Walsh; 1 Audra Potz; 1 Kay Lois Henry; 1 Lauren Barack; 2 Deanna Bellandi; 1 Charles Hoskinson; 1 Jeff Becker; 1 Teresa Burney; 1 Stephen Nohlgren; 1 Khalil Hachem; 1 David Olinger; 2 Betty Jean Miller; 1 Terry Tomalin; 1	
1996	Jeff Klinkenberg; 1 Betty Jean Miller; 1 Terry Tomalin; 2 Monica Davey; 1 Kit Troyer; 2 Cheryl Ross; 1 Charles Hoskinson; 2 David Olinger; 10 Sharon Kennedy Wynne; 1 Lisa Pelamati; 1 Gregory Enns; 2 David Ballingrud; 1 Amelia Davis; 1 Robin K. Ray; 1 Amy Ellis; 2 Roger Clendening II; 1 Julie Hauserman; 1 David Ho; 1 Brian Stearman; 1 Dan DeWitt; 1 Berry Walker; 1 Bob Puccinelli; 1	43

1997	Sue Landry; 1 David Olinger; 2 Helen S. Popkin; 1	9

APPENDIX 4. ALPHABETICAL LISTING OF JOURNALISTS WHO COVERED RED TIDE, 1953-1997

Journalist	Date	Total
Mark Albright	6/15/95	1
Chuck Albury	10/5/57	1
Stevan Allen	5/24/87	1
Cesar Alvarez III	4/16/89	1
David Ballingrud	4/22/96	1
Lauren Barack	6/13/95 8/3/95 (w/ Tim Roche)	2
Jack Barrett	9/1/78	1
Jeff Becker	8/4/95	1
Deanna Bellandi	7/14/95	1
Bob Bender	7/27/71 8/3/71	2
Deborah Blum	8/11/80	1
Dick Bothwell	9/3/76	1
Barry Bradley	4/22/82	1
Rick Bragg	4/8/89	1
Teresa Burney	8/14/95	1
Angel Castillo Jr.	11/21/74	1
Joe Childs	4/22/76	1
Journalist	**Date**	**Total**
Roger Clendening II	5/18/96	1
Marla Cone (*Los Angeles Times*)	5/22/94	1
Alan Cowan	7/26/71	1
Karen Datko	4/9/89 3/26/89	2
Jane Daugherty	7/15/71	1
Monica Davey	9/27/94 9/20/94 3/17/96	3
Amelia Davis	5/4/96	1
Dan DeWitt	9/25/96	1
Roger Downey	7/8/71	1
Amy Ellis	5/15/96 5/16/96	2
Gregory Enns	4/3/96 6/13/96	2
M.P. Fleisher	7/12/71 (w/ Roger Downey)	1
Jodi Fleisig	8/14/82	1
William Fox	5/23/87	1

Journalist	Date	Total
Robert Fraser	7/6/71 7/5/71	2
Tom French	12/28/87	1
John Gardner	10/2/59 10/3/59 10/6/59 10/11/59 1/5/63	5
Alan Goldstein	4/13/89 (w/ Mark Albright)	1
Laura Griffin	11/23/94	1
Philip S. Gutis (*New York Times*)	5/14/88	1
Khalil Hachem	9/1/95	1
Bill Hager	4/21/63	1
Warren Hart	5/20/95	1
Joe Hartman	9/6/78 9/13/78 9/14/78 9/15/78 (w/ Big John Arndt & G.B. Knowles)	4
Julie Hauserman	7/12/96	1
Jean Heller	6/14/95	1
Kay Lois Henry	6/21/95	1
Pat Hiatte	7/7/71 7/8/71 8/3/71 8/5/71	8
Pat Hiatte (cont.)	8/6/71 8/7/71 8/12/71 8/18/71	
Larry Holmgren	10/3/57	1
David Ho	7/19/96 (w/ David Olinger)	1
Robert Hooker	7/11/71 7/27/71 7/28/71 8/9/71	4
Charles Hoskinson	8/1/95 4/23/96 6/4/96	3
Helen Huntley	6/13/80 6/20/80	2
Bruce Ingersoll (*Wall Street Journal*)	4/21/88	1
Mike Jackson	5/27/95	1
Mark Journey	3/25/89	1
Beirne Keefer	5/26/87 5/15/87 (w/ Debbie Luciani) 5/12/87 10/7/88 (w/ Debbie Luciani)	6

Journalist	Date	Total
	4/14/89 (w/ Debbie Luciani) 4/13/89	
Nancy Klingener	2/22/95	1
Jeff Klinkenberg	9/17/78 10/7/87 5/4/96	3
Richard Koenig	8/1/80 (w/ Betty Kohlman)	1
Betty Kohlman	10/4/77 10/5/77 6/25/80 (w/ Jonathan Susskind) 6/27/80 (w/ Theresa White) 8/24/82 5/25/84 5/26/84 (w/ Christopher Smart) 5/29/84 6/7/84 6/22/84 (w/ Ed Marks)	10
Bob Kyle	7/11/71	1
Sue Landry	4/9/89 (w/ Alicia Caldwell, Lisa Grace Lednicer, Heddy Murphey, Jeff Sklansky) 4/13/97	2
Lisa Grace Lednicer	10/24/89	1
Journalist	**Date**	**Total**
James Lewis	4/4/63 4/6/63 4/7/63 4/10/63 4/15/63 4/20/63 6/4/63 6/16/63 2/28/64 3/25/64 9/4/64 7/22/65 1/18/66 3/31/66	14
Ed Marks	5/31/84 6/22/84 (w/ Betty Kohlman) 6/25/84	3
Steven A. Marquez	8/3/82	1
Red Marston	8/20/57 4/5/63 5/3/63 9/10/63 8/28/64 7/15/71 8/24/71	7
Betty Jean Miller	6/12/87 8/31/95 5/8/96	3

T. Christian Miller	6/7/95	1
Dick Morgan	9/28/57 10/3/57 10/4/57 10/6/57 10/12/57 11/30/57	6
Journalist	**Date**	**Total**
Bill Moss	11/5/85 5/12/89 (w/ David Rogers)	2
Stephen Nohlgren	8/27/95	1
Carolyn Nolte	7/4/71 7/15/71	2
Wilma Norton	4/11/89 (w/ Patty Curtin, Mike Jackson, Marie Tessier)	1
David Olinger	10/17/95 10/21/95 12/2/96 2/7/96 2/27/96 4/9/96 4/17/96 (w/ Jeff Klinkenberg) 4/19/96 5/14/96 5/31/96 12/2/96 12/3/96 1/25/97 1/4/97	14
Charles Patrick	10/2/76	1
Lisa Pelamati	3/23/96	1
John Pennington	11/19/78	1
Helen A.S. Popkin	7/7/97	1
Journalist	**Date**	**Total**
Bob Port	10/30/85	1
Audra Potz	6/18/95	1
Bob Puccinelli	10/5/96	1
Ed Quioco	5/26/95 6/2/95 (w/ Tim Roche)	2
Robin K. Ray	5/12/96	1
Craig Roberton	8/13/82	1
Tim Roche	9/21/94 5/11/95 (w/ Peter Wallsten) 5/12/95 (w/ Peter Wallsten) 5/30/95 6/7/95	5
David Rogers	8/23/88	1
Cheryl Ross	5/20/95 (w/ Tim Roche) 4/6/96	2

Felicia Rosser	11/8/94	1
James Ryan	3/8/71 7/8/71 7/9/71 7/10/71 7/13/71 7/14/71 7/15/71 10/2/71	8
Journalist	**Date**	**Total**
Judy Sedgeman	4/7/75 8/1/71	2
Chris Sherman	10/26/89	1
Christopher Smart	5/26/84 (w/ Betty Kohlman)	1
Tim Smart	1/24/80	1
Vernon Smith, Jr.	6/23/84	1
Brian Stearman	8/18/96	1
Jerome Stockfish	10/6/94	1
Kathy Subko	12/27/87	1
Ron Suskind	11/3/85	1
Jonathan Susskind	6/24/80 7/11/80 8/5/80 8/6/80 8/7/80	5
Paul Tash	9/12/78 9/15/78 9/17/78 9/23/78 9/27/78	5
Calvin Taylor	8/2/71	1
Stuart Thayer	10/16/74	1
Terry Tomalin	10/7/94 6/16/95	4
Journalist	**Date**	**Total**
	3/8/96 7/12/96	
Kit Troyer	4/25/95 5/16/95 6/13/95 9/15/95 4/24/96 (w/ David Olinger) 9/8/96	6
Norma Wagner	4/10/89	1
Berry Walker	9/27/96	1
Peter Wallsten	5/11/95 5/14/95	2
Amy Walsh	6/16/95	1
Joshua Weinstein	4/14/89 4/12/89 4/4/89 (w/ Mike Jackson) 3/28/89	4
Theresa White	6/28/80	1
Vanessa Williams	9/7/78 9/8/78 9/9/78	3

Dail Willis	10/21/88	1
Sharon Kennedy Wynne	3/16/96	1

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