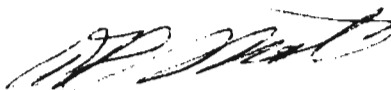


RED TIDE RESEARCH  
at the  
MOTE MARINE LABORATORY  
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A FIVE-YEAR STATUS REPORT

Prepared by

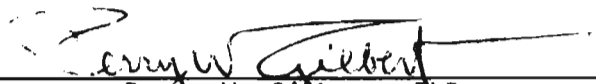
H. David Baldridge, PhD  
Senior Research Associate  
Red Tide Program Manager, 1972-1977

Approved by:



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William R. Mote  
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Mote Marine Laboratory



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Perry W. Gilbert, PhD  
Director  
Mote Marine Laboratory

June 30, 1977

## HISTORY AND PROGRAM PHILOSOPHY

The essence of the Mote Marine Laboratory's capability for conducting basic research in marine science lies in its ready access to a living sea. The laboratory and the sea are one. Marine biological research is patently dependent on an abundant supply of healthy live specimens. So it was, until the late spring and summer of 1971. It was then that an intense, highly toxic outbreak of red tide devastated not only local waters but also killed the experimental animals in aquaria and shark pens at the Mote Marine Laboratory (MML), bringing essentially all scientific programs to a standstill. Out of an understandably strong desire to protect our valuable specimens from future such crippling assaults, there soon developed at MML an intense scientific interest in the phenomenon of red tide itself.

Within a few months, Dr. Perry Gilbert (MML's Director) had developed a general research plan and began to probe potential sources of funding. Proposals to a number of private foundations and government agencies produced favorable, encouraging comments but no immediate support.

Then, as so often in the past, Florida marine science benefited from the foresightedness and generosity of Helen and William Vanderbilt of Englewood, Florida and Williamstown, Massachusetts. In November 1971, life was breathed into MML's budding Red Tide Program by a sizable contribution from the Vanderbilts that would serve as seed money in attracting additional funding. Response was prompt, for in mid-March 1972, core support of what developed into a five-year program was announced by an initial \$50,000 grant from the William G. Selby and Marie Selby Foundation of Sarasota.

The Mote Marine Laboratory Red Tide Research Program began in earnest on 1 April 1972.

It would be extremely negligent not to point out that much very fine research on Florida red tide had been and continues to be conducted by highly competent scientists in various laboratories of this state's public and private university systems and the Marine Research Laboratory of the Florida Department of Natural Resources. In addition, a number of scientists, many of whom had origins in Florida, continue research on our form of red tide in laboratories throughout the country. The extreme scientific complexity and multidisciplinary breadth of the problem of red tide is clearly attested to by the rapidity with which MML's relatively recently committed study programs have been assimilated into the overall Florida red tide research effort.

Red tide research at MML originated as a joint, collaborative effort with the University of South Florida (USF). All phases of the MML program continue to be developed in close association and/or collaboration with the Marine Research Laboratory (St. Petersburg) of the Florida Department of Natural Resources and various departments of USF in Tampa and St. Petersburg. Costly duplication has been particularly avoided in seeking avenues for direct interaction between MML and other laboratories actively involved in research on Florida red tide.

MML has been particularly interested in developing with the National Aeronautics and Space Administration (NASA) collaborative efforts that bring space technology to bear on the problem of early detection and tracking of red tide in Florida waters.

For the fourth consecutive year, the Florida Legislature has appropriated \$25,000 to MML in partial support of the Red Tide Research Program, "in recognition of the long-range significance to the citizens of Florida of continued basic research on red tide". Details of experimental design and methodology involved in our state-supported studies regularly are made available to scientists of the Florida Department of Natural Resources and the University of South Florida through progress reports prepared as part of contractual arrangements used to convey state funds to MML.

Serving further to assure coordination of research effort, Dr. H. D. Baldrige (Red Tide Program Manager at MML) and Dr. Larry Freeberg (MML Biological Oceanographer), successively, have been members of the seven-member Ad Hoc Council for Red Tide Research of the Florida Department of Natural Resources. This panel is specifically charged with responsibility to the Florida Legislature for evaluation and coordination of red tide research in the State of Florida.

The MML Red Tide Research Program was planned from the outset as a five-year probe into those intricacies of the problem where significant scientific contributions would be more likely accomplished on a realistic time frame in terms of expertise at our command. Continuing long-term studies would be pursued thereafter in those areas where understanding required additional research at the basic level.

### RED TIDE: THE PROBLEM

Massive blooms of toxic marine organisms in Florida waters give rise at irregular intervals to a devastating phenomenon called "red tide". The term "red tide" is loosely applied to regions of

biologically discolored seawater often associated with signs of extreme toxicity. When conditions in the sea are optimum for growth and/or aggregation of certain poisonous microorganisms, dinoflagellates in particular, populations rapidly increase by several orders of magnitude. Resulting concentrations of associated toxins then reach levels that are hazardous for marine life and for man.

The unarmored dinoflagellate, Gymnodinium breve Davis, is the primary causative agent of noxious red tides in waters of the Gulf of Mexico along the central west coast of Florida. Fish kills commence as organism concentrations rise above about 250,000 per liter and become massive with higher counts that at times reach many millions per liter. The unsightly and unsanitary, malodorous conditions produced by tons of dead fish at the water's edge during such "blooms" place severe economic stress upon adjacent tourist-oriented communities. More importantly, the potential for serious human health problems has now become acutely apparent.

Losses of the order of \$20,000,000 were reported by private and public interests for the relatively mild red tide of 1971. During the course of the 1973-1974 red tide, losses directly attributable to red tide were very difficult to assess, for they were compounded and somewhat masked by concurrent economic stresses related to rampant inflation and an intense gasoline shortage. Nevertheless, damage to Florida tourist interests inflicted by the 1973-1974 red tide was conservatively set in excess of \$15,000,000.

Public health is threatened by Florida red tide in a variety of ways. First, there are the obvious consequences (sickening sight, odor, and attractiveness to disease-carrying insects) of widespread carrion on public beaches. Another annoyance of possible real significance to persons already suffering from respiratory disease is the highly irritating airborne matter that is generated by wave and surf action and carried inland by winds. The third, more serious effect of true life-threatening potential has to do with ingestion of toxin-containing shellfish. Reports of human neurotoxic shellfish poisoning during Florida red tide began to appear in the scientific literature around 1965. Several people were poisoned to the point of requiring emergency treatment and/or hospitalization in the Sarasota area during the red tide of 1973-74. Symptoms in one Sarasota boy, who in 1973 ingested toxic clams, reached the stage of respiratory arrest and were considered of definite life-threatening intensity.

In recognition of the serious ingestion toxicity hazard, the Florida Division of Health is presently committed to a costly program of routine surveillance of potential red tide water areas, backed up by shellfish analyses in the laboratory for neurotoxic indications.

Red tide in Florida waters is thus widely recognized to be of very serious, increasing significance to the economic community and potentially disastrous in terms of human personal and public health.

### GENERAL PROGRAM DEVELOPMENT

Our first year saw development of a multi-faceted program involving a variety of scientific disciplines, as outlined in the block diagram of Figure 1. This initial program admittedly was very ambitious in scope, for its primary purpose was to provide for early delineation of broad problem areas to which concentrated attention would become increasingly directed. Funding limitations governed the degree to which it could be implemented. Nevertheless, as detailed later, very significant progress was achieved in a number of these important areas of initial concern during the short span of five years.

Matters of primary interest and study included: (a) the pressing need for reliable means for predicting red tide in Florida waters, (b) monitoring of affected waters offshore for recognition of chemical and physical changes associated with onset of red tide, (c) examination of nutritive requirements of G. breve, the primary causative agent of Florida red tide, (d) further consideration of the control of red tide in terms of practicability and possible new approaches, (e) amelioration of red tide effects upon human comfort and sensibilities, and (f) comprehensive analysis of the economic impact of red tides on affected communities.

Very early in the MML program, association was developed with the National Aeronautics and Space Administration (NASA) in regard to early detection of G. breve blooms by remote sensing techniques. Both marine and space scientists generally agree that capability for reliable detection of incipient red tide, in the form usually experienced in Florida waters, is beyond the present state of the art in both recognition of relevant parameters to be sensed and the development of applicable instrumentation. To this purpose, Dr. H. D. Baldrige of MML composed in May of 1974 a draft of a letter (Appendix A) that was subsequently sent by Florida's U.S. Senator Lawton Chiles to the NASA Administrator, Dr. James Fletcher. Assistance was thereby formally requested of NASA in a number of areas of space science of importance to red tide research in Florida.

To this purpose, the NASA/Goddard Space Flight Center in Maryland subsequently initiated a research program dealing with early detection of Florida red tide. The major objectives of their program are (a) to develop remote sensing techniques capable of unambiguously identifying G. breve blooms in remote multispectral imagery

# RED TIDE RESEARCH PROGRAM

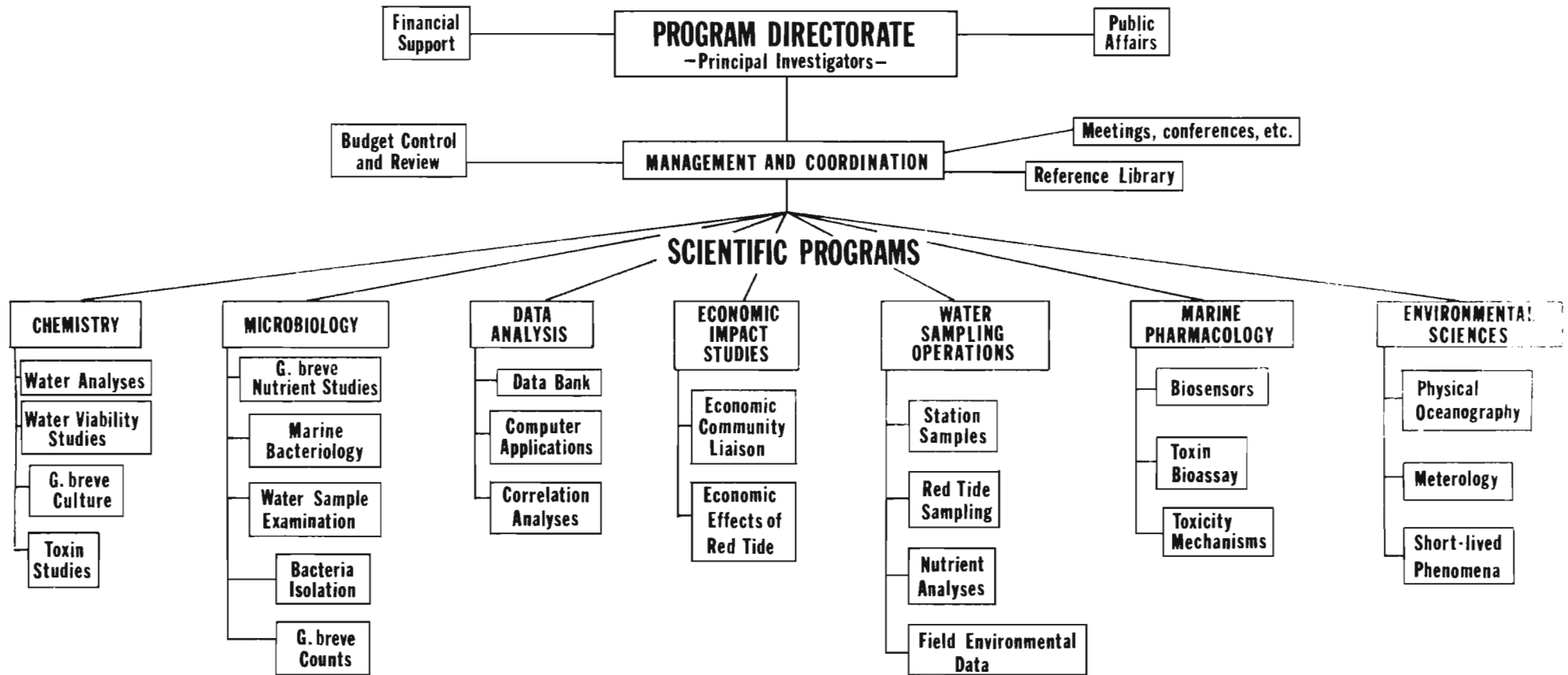


FIGURE 1

of Florida coastal waters, and (b) to assess the feasibility of using these techniques to generate maps of G. breve distribution from aircraft or satellite remote imagery.

In the fall of 1974, Dr. Larry R. Freeberg joined the staff of MML with primary responsibility for establishing and conducting a research program in phytoplankton ecology. Freeberg received his PhD in Biological Oceanography from Texas A&M University, where he studied under Dr. William Wilson, noted authority on Florida red tide.

A 12 x 50 foot mobile laboratory (Figure 2) was fully outfitted for Freeberg's phytoplankton studies. The main (12 x 20 foot) laboratory room (Figure 3) provides space for instrumentation as well as a wet area for the preparation of media and the handling of water samples. At one end of the laboratory, two (2) walk-in temperature-controlled culture rooms were developed (Figure 4). Necessary insulation was installed and temperature-control devices were fitted and thoroughly tested. Selby funding provided most of the capital equipment in support of this phytoplankton study, including a laminar flow cabinet (Figure 5), water distillation equipment, fluorometer, etc. The very difficult, time-consuming problem of counting rapidly moving red tide organisms in field samples and laboratory cultures has been made much easier by the recent acquisition of a Coulter Counter. This costly instrument, which counts the tiny organisms electronically, was paid for by generous donations from individuals, local tourist-oriented businesses, and the Save-Our-Bays Association.

Reflecting the converging breadth of emphasis intentionally designed into the MML program, activities over the 1972-1977 period gradually evolved from the generalities of Figure 1 to the specifics of Figure 6.

#### PROGRAM HIGHLIGHTS

Economic Impact Studies. MML research economist Eugene Habas co-authored with Claire Gilbert two scientific papers on intensive analyses of economic effects of red tide (Environmental Letters, 6(2), 139-147, 1974 and Proceedings of the First International Conference on Toxic Dinoflagellate Blooms, Boston, 1974, pp. 499-505). Aside from the direct human health effects, red tide in Florida is primarily an affliction of the economic community. The studies of Habas and Gilbert are the first and only valid assessments of the magnitudes of economic blows dealt periodically by red tide to the seven most affected counties bordering the west coast of Florida. Losses of the order of \$20,000,000 were reported for the relatively mild red tide of 1971, with considerably greater economic damage expected for more intense and prolonged blooms.



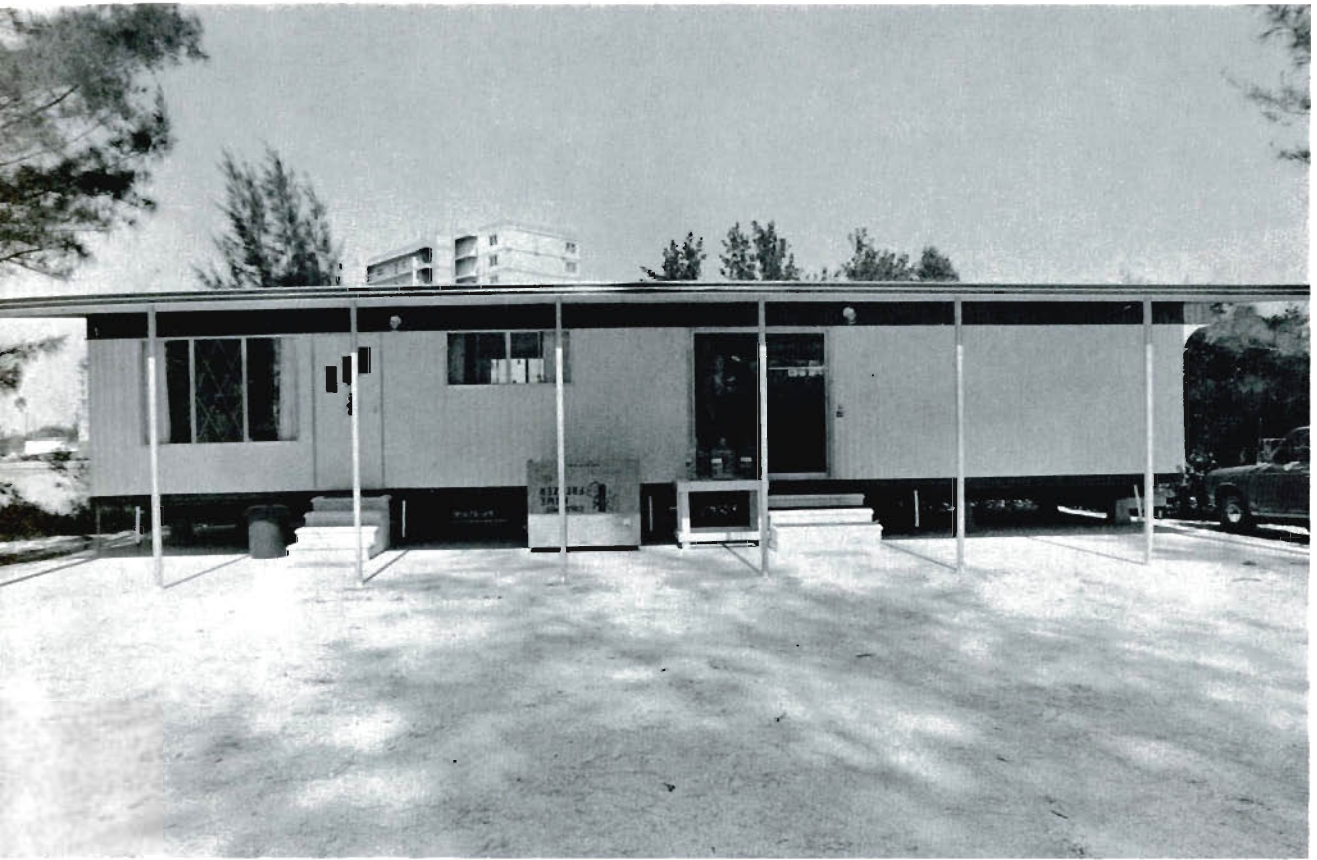


FIGURE 2. A 12x50 foot mobile laboratory outfitted as a well-equipped facility for the study of plankton ecology. Note the 10x50 foot sheltered slab area used for gross wet work and outside storage.



FIGURE 3. Working areas of the main laboratory room, including water purification equipment and a high volume autoclave for use in media preparation, as well as bench and sink spaces.



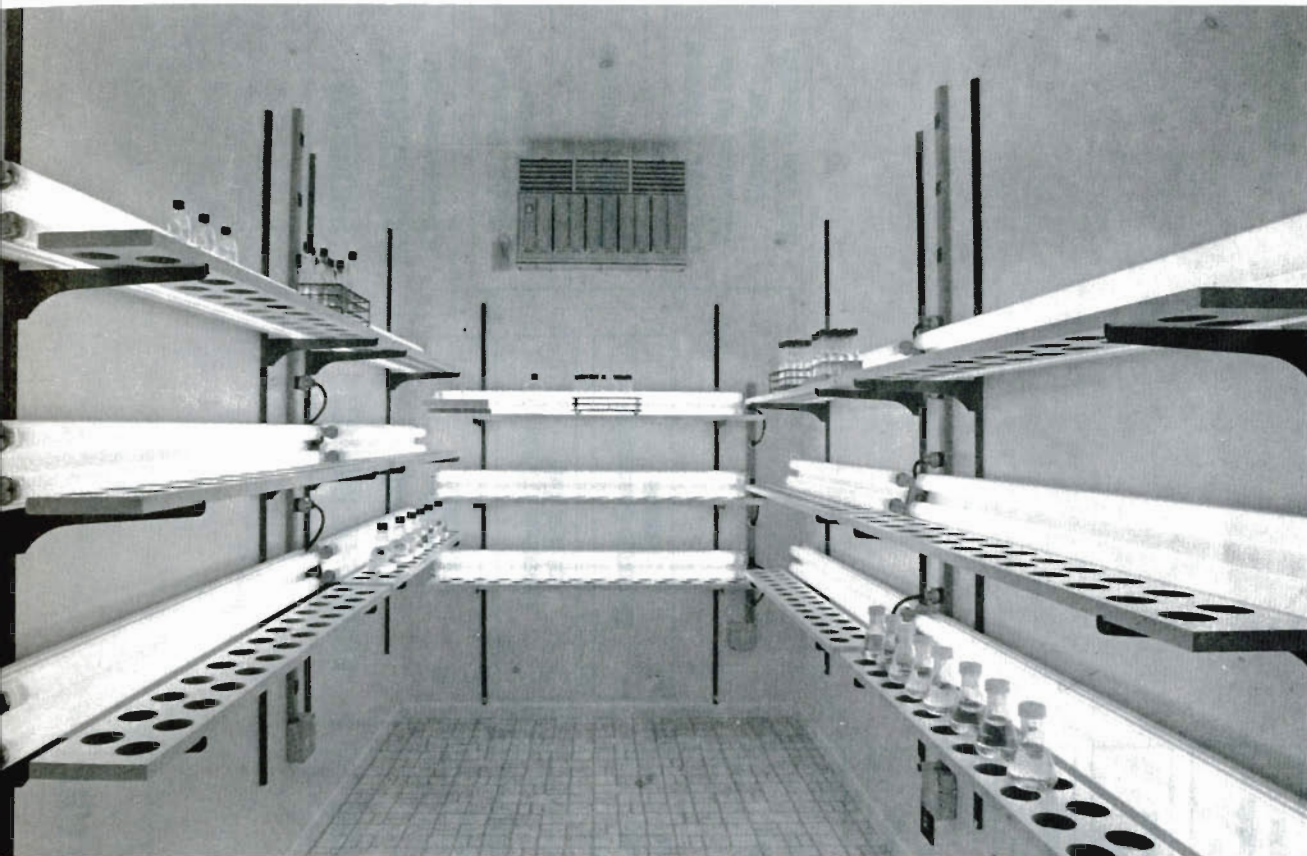


FIGURE 4. One of the twin walk-in temperature-controlled culture rooms designed and developed for phytoplankton studies. These environmentally controlled spaces operate over a temperature range of about 16 - 35 degrees C., with a control capability of about plus or minus 1 degree C.



FIGURE 5. The MML laminar flow cabinet is essential to the isolation, maintenance, and propagation of pure cultures of phytoplankton and associated marine organisms. Other vital items of major equipment made available by MML included the pictured microscopic and fluorometric instrumentation.

# PROGRAM COORDINATOR

H. David Baldridge, PhD

## PHYTOPLANKTON ECOLOGY

Larry Freeberg, PhD  
Anne Marshall, MS  
Marian Klein, MA

Isolation of  
Microorganisms from  
Gulf Waters

Development of  
Pure Cultures

Nutrient Studies

Biochemical  
Interrelationships of  
Marine Phytoplankton

Chemistry  
Mike Hoyl, MS

## DATA ANALYSIS

H. David Baldridge, PhD

Correlation  
Analyses

Red Tide  
Prediction

## REMOTE SENSING

Larry Freeberg, PhD

National Aeronautics  
and Space Administration  
(NASA)

Marine Research  
Laboratory, Florida  
Dept. of Natural  
Resources

Surface Truthing  
Space Satellites  
U-2 Aircraft

Water Sampling  
Operations  
MML Staff

Chemistry  
Mike Hoyl, MS

Bioassay  
Anne Marshall, MS

Red Tide  
Organism Counts  
Marian Klein, MA

## ECONOMIC IMPACT STUDIES

Eugene Habas  
Claire Gilbert

Economic Effects  
of Red Tide

Economic Community  
Liaison

## PROGRAM MANAGEMENT

H. David Baldridge, PhD

Budget Control  
and Review

Research Proposals

Fla. Dept. of Natural  
Resources Ad Hoc  
Council for  
Red Tide Research

FIGURE 6

In the 1971 red tide, fishing, both commercial and sports, was seriously affected. Boating, surfing, water skiing, and all other water sports ceased. Beaches were taken over by dead fish and emptied of people except for gangs of county prisoners, road crews, municipal employees, and volunteers who worked with shovels, tractors, bull-dozers, and even road graders to bury the dead fish. Bait stands, boat rentals, fishing camps, beach concessionaires, surf shops, sportswear boutiques, marinas, boat yards, and tackle stores were affected. Ashore, hotels, motels, and rental cottages were avoided by their normal clientele and in some instances were virtually evacuated. Further afield, bus and airlines, gas stations, restaurants, especially fish and chowder houses, fish markets, even grocery stores felt the impact. The ramifications were incalculable.

The adverse economic effects in the seven counties took place during decidedly different but overlapping time frames. The red tide was initially observed in Collier, Lee, and Charlotte Counties during the first week in June, 1971. Ten days later, moving northward, it hit the beaches of Sarasota and Manatee Counties. By the end of June, Hillsborough and Pinellas Counties were affected but by then it has subsided in Collier, Lee, and Charlotte Counties. In its inexorable trek north, it reached its peak in Tampa Bay on July 15.

Similar overlapping periods of adverse aftereffects lasted for about 50 days beyond the time the red tide had spent itself in each region. While the national press, radio, and TV gave extended coverage to the Florida red tide during its incidence, there was regrettably no well-publicized announcement in early August that it was over. Various operators of motels, beach cottages, and marinas reported they received calls from prospective customers inquiring about the red tide, well beyond this 50-day period. In the last area affected, these calls continued in diminishing degree until the end of 1971. Data collection on the red tide's economic impact was necessarily made more difficult by these undefined perimeters of time.

Two factors "colored" the data accumulated: (1) the economy of the coastline areas of all seven counties is, in diverse degrees, subordinate to the business, commercial, and/or agricultural economy of the rest of the county, and (2) 1971 was a year of substantial growth for all seven counties. The overall prosperity cushioned the negative impact of the red tide. Shore-based businessmen knew they had been hurt, but retailers in the aggregate simply were not aware that they had actually "lost" large volumes of business. For instance, monthly sales tax collections by the state of Florida indicated no marked fluctuations in business volumes in Sarasota County during the months (June and July) the red tide was present.

A questionnaire was sent to Chambers of Commerce in the affected areas. The response was numerically disappointing, and it became necessary to seek information from other sources. Personal interviews with the proprietors of resorts and other businesses bordering the Gulf yielded many valid data, as did the local newspapers' day-to-day coverage. Especially valuable for extrapolation of these data were studies in the publications from Florida's Departments of Commerce and Business Regulation.

The estimates of damage so derived, while admittedly not "hard facts", could probably be substantiated, and perhaps implemented, by direct communication with individual proprietors of businesses affected by the 1971 red tide.

Table 1 summarizes the estimated losses by the business community and the costs of beach cleanup. The first column of data in the table estimates losses on a daily basis. The second assumes that the damage suffered in the first seven categories extended over a total of 50 days, or about seven weeks. It could be argued that the maximum economic "pain" did not last a full seven weeks, but since there was "hurt" for several months after the tide, the 50-day period was arbitrarily chosen to encompass the months-long lingering effects. Commercial fishing revenues and beach cleanup costs are calculated for a 20-day period.

TABLE 1

Summary of Estimated Losses - Seven Counties  
(Collier, Lee, Charlotte, Sarasota, Manatee, Hillsborough, Pinellas)

<u>Categories</u>	<u>Per Day</u>	<u>Duration</u>	<u>Total</u>
Hotel/motel revenues	\$120,000	50 days	\$ 6,000,000
Restaurants, other eating places	50,000	50 days	2,500,000
Amusements (movies, marinas, charter boats, theaters, etc.)	45,000	50 days	2,250,000
Clothing, footwear retailers	37,500	50 days	1,875,000
Food/drink retailers	37,500	50 days	1,875,000
Others (drugs, gifts, gasoline, photographic supplies, laundries, other business services, etc.)	77,500	50 days	3,875,000
Subtotal (rounded)	\$370,000		\$ 18,500,000
Purveyors of hotel/motel supplies	3,500	50 days	175,000
Commercial fishing revenues	25,000	20 days	500,000
Beach clean-up costs	11,000	20 days	220,000
Grand Total	\$409,500		\$ 19,495,000
Rounded Figures	\$400,000		\$ 20,000,000

Predictably, a future red tide of the dimension of that of 1971 will inflict a minimum of 35% more economic damage. A red tide of greater dimension OR one that strikes in winter OR one that lasts longer OR one more extensive geographically OR any combination of the above could inflict economic damage easily triple that of 1971.

The red tide of 1973-1974 on the west coast of Florida was almost open-ended, breaking out sporadically and capriciously, widespread in time and place. It was first noticed on October 22, 1973, 8-10 miles offshore between St. Petersburg and Longboat Key. The first shoreline involvement was a massive fish kill at Boca Grande on October 29, 1973. Nearly a year later in September of 1974 four fish kills occurred on the northwest Florida coast between Panama City and Pensacola. While generally moderate, some excessive counts of G. breve occurred in small patches. Twenty-two million/liter were reported at Boca Ciega Canal near Redington Beach on April 3. Warm Gulf waters were blamed for its continual reappearance through the winter. In contrast to the red tide of 1971, this one occurred predominantly in the winter months when tourism is normally at its peak. Fortunately, national publicity was minimal, so the economic damage wrought is due solely to its prolonged severity.

During the course of the 1973-1974 red tide, two factors, a shortage of gasoline and increasingly high interest rates, played havoc with the economy of the west coast and masked losses attributable to the red tide alone. The east coast of Florida suffered from both the gasoline shortage and high interest rates but NOT from the red tide and, to a limited degree, served as a control to give a better perspective to the assessment of the damage due solely to the red tide on Florida's west coast.

Indications were that the Florida red tide of 1973-1974 inflicted on the tourist industry alone a loss conservatively set at \$15,000,000. Furthermore, losses imposed upon commercial fishing, real estate, and construction possibly equaled or even exceeded those suffered by the tourist industry.

Again, these studies by Habas and Gilbert, to our knowledge, are the only surveys that have ever attempted to measure broadly the impact of red tide on the economic community of west central Florida.

Water Sampling Operations. Regular weekly sampling at an average of 14 seawater stations was a major part of our early efforts to identify chemical and/or physical triggers of red tide blooms. Approximately 2000 samples were collected during three years (May 1972 - May 1975) of weekly monitoring of the waters from Tampa Bay to Charlotte Harbor at the following sampling stations:

## Area 1, Charlotte Harbor (eight stations):

<u>Station</u>	<u>Location</u>
11	End of Mote Marine Lab dock at Placida Harbor.
12	Southwest end of Boca Grande toll bridge.
13A/B	Gasparilla Pass. Station 13A tended by auto at southeast end of Boca Grande Bridge. In favorable weather, station 13B sampled instead by boat standing well into pass waters.
14A/B	Boca Grande Pass. Station 14A tended by auto at southwest end of Belcher Oil Dock. In favorable weather, station 14B sampled instead by boat standing well into pass waters.
15	Peace River. Southwest end of Punta Gorda bridge (Howard Johnson dock).
16	Discontinued 6/4/73; (Peace River at SR 761 bridge in Desoto County).
17	Myakka River. Southwest end of El Jobean bridge.
18	Discontinued 6/4/73; (Myakka River at southwest end of El Jobean bridge).
19	Coral Creek at Stew Springer's dock.
110	Gulf of Mexico off Boca Grande Pass. Four (4) miles off Boca Grande Pass in favorable weather, otherwise sampled from shore.

## Area 2, Sarasota County (five stations):

21	Midnight Pass between Siesta Key and Casey Key.
22	Big Pass between Siesta Key and Lido Key.
23	New Pass between Lido Key and Longboat Key.
24	Gulf of Mexico about four (4) miles off Lido Key. Sampled only during favorable weather.
25	Gulf of Mexico at seaward end of Venice Fishing Pier.

MML counts of red tide organisms in these samples were made available to several state, county, and city laboratories in our area and constituted the primary basis for judging the onset, intensity, and demise of G. breve blooms in local waters during the three-year sampling period. Some 20-25,000 bits of chemical and physical information (analyses, measurements, etc.) on water quality factors have been generated from our samples, principally by analyses conducted at the University of South Florida under the direction of Dr. Harold Humm. Many of these data were made available to Dr. Dean Martin of the Chemistry Department, University of South Florida, for MML-funded computer studies designed to detect interrelationships and correlations existing between various chemical and physical parameters.

Over a year of control data were generated in our water monitoring program before commencement of the 1973-1974 red tide. We then bridged the bloom period by collecting and analyzing water for another year following that relatively intense outbreak. There are in these data suggestions of gradual trends in water chemistry, particularly acidity levels, of possible stage-setting significance in onset of red tide. Also, there was observed prior to the 1973-1974 bloom a curiously prolonged period of general chemical quiescence, in strong contrast to the chemical discord noted during the earlier non-bloom year. Even though thousands of measurements were made, our sampling data on the whole statistically represent only three conditions, one season with red tide and two without. The value of these data will increase significantly as other blooms occur and especially when considered in the context of current MML field observations and laboratory studies on growth requirements for G. breve.

In late 1972, a northerly bound hurricane moved parallel to the shoreline of west central Florida and caused general, prolonged disruption of local water chemistries. Unfortunately, the question still remains as to whether subsequent chemical analyses of seawater samples reflected slow recovery from the disturbance of the hurricane or a gradual chemical stage-setting for the red tide bloom of 1973, or both.

Microbiology. Dr. E. Edward Evans, MML's microbiologist, reported (Environmental Letters, 5(1), 37-44, 1973) that, "while G. breve is generally recognized as the principal cause of Florida red tide, insufficient attention had been devoted to bacteria associated with this dinoflagellate". Evans' laboratory studies on the role of bacteria in red tide blooms led him to hypothesize that growth of G. breve during a bloom is stimulated by the concurrent or prior growth of marine bacteria which supply known vitamin requirements and perhaps other growth factors. Also, he considered the red discoloration of intense blooms to be due not to G. breve but to chromogenic bacteria. Such bacteria were actually isolated from seawater samples taken during the 1971 red tide off Siesta Key, Sarasota.



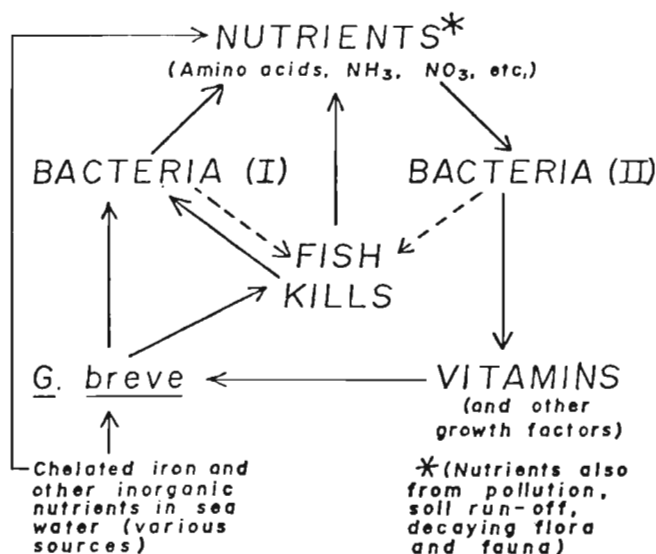
Red discolorations were produced when these bacteria were grown in various synthetic laboratory media. Furthermore, samples taken during a minor G. breve bloom in 1972 strongly suggested a possible mathematical correlation between counts of bacteria and those of G. breve. Interestingly, none of the bacteria from this bloom were red, only yellow to orange.

Evans was not content with accepting bacteria only in a passive role in red tide blooms, producing discoloration and little else. He suggested that certain species of bacteria, which are not necessarily chromogenic, multiply in sea water prior to or concurrently with blooms of G. breve. Their role in the nutrition of G. breve would likely be to supply known vitamin requirements (biotin, thiamine, and B<sub>12</sub> activity) or to supply other growth factors yet to be identified. Bacterial growth could be triggered by nutrients in tidal currents or upwellings, perhaps soluble proteinaceous material from small localized fish kills due to factors other than G. breve. Nutrients could also arise from soil runoff or sewage and industrial pollution.

Once the process has begun in a small way, perhaps localized and unnoticed, it develops into a repeating, self-duplicating cycle which is illustrated in Figure 7.

FIGURE 7

## The Red Tide Cycle



While the role of G. breve in Florida red tide seems well established, Evans concluded that there is increasing evidence for participation of marine bacteria and perhaps other microorganisms in the following ways:

1. Growth of non-chromogenic marine bacteria (II) is stimulated by the above nutrients. The bacteria synthesize biotin, thiamine, vitamin B<sub>12</sub> and other growth factors which in turn stimulate a rapid bloom of G. breve. With all other growth requirements for G. breve known to be present in sea water (although concentrations will vary), attention turns towards bacterial-synthesized growth factors as a possible trigger for a bloom.

2. As the first fish kill occurs following the first cycle of G. breve multiplication, saprophytic bacteria (I) (which may be red) appear in response to proteinaceous material from dying fish, invertebrates or even disintegrating G. breve cells. The discolored water is due to bacteria.

3. Toxins from either type of bacteria might act synergistically with the toxin of G. breve to kill fish.

4. Cycles of red tide would tend to be self-duplicating. Repeating and/or overlapping cycles might be obscured in a massive bloom. Chromogens might be inapparent during a minor bloom, and thus the water would not appear discolored.

Evans conceded his hypothesis to be of a preliminary nature, awaiting experimental verification during future G. breve blooms. It is regrettable that continued aggravation of a severe allergic condition caused Dr. Evans to discontinue his work at MML and relocate in California.

Dr. H. David Baldridge and Mrs. Marian Klein developed a simplified means for counting the high populations of G. breve associated with major red tide outbreaks (Environmental Letters, 7(1), 31-38, 1974). Tabulating difficulties experienced as the live organisms swim rapidly past the microscope field of view are overcome by non-disruptive immobilization thru the use of a readily available drug. During such blooms, concentrations of G. breve cells rise from the routine 100-1000 per liter to fish-killing levels of at least hundreds of thousands per liter. Counts approaching 100 million per liter are occasionally found in pockets of very intense blooms.

Although subject to morphological variation in response to environmental changes, G. breve cells are generally slightly broader than long, with these dimensions being of the order of 20-40 microns. They are strongly concave ventrally and convex dorsally, with a thickness of only about 13 microns. G. breve when mobile, resemble falling

leaves as they tumble thru the water at a rate of about one meter per hour.

These characteristics combine to present severe qualitative and quantitative difficulties to microscopists attempting to identify and count G. breve in the large numbers of samples necessarily examined during blooms of fish-killing proportions. A confusing variety in appearances of individual organisms results from differences in attitude assumed by immobile G. breve. Additionally, mobile individuals make it very difficult to accurately count the high concentrations of organisms found during a red tide. True values are particularly desirable at such times because of possible correlation with concurrent changes in a variety of physical and chemical parameters.

To this end, Baldrige and Klein developed means for rapidly immobilizing G. breve without causing significant cell destruction. G. breve was found remarkably resistant to disintegration by vigorous handling, and non-disruptive immobilization was satisfactorily achieved by such physical processes as low speed centrifugation and vortex-type stirring. However, chemical methods were found to provide more simple, rapid, easily controlled procedures. Non-disruptive immobilization resulted from addition of a variety of inhibitory drugs such as tubocurarine, atropine, strychnine, malathion, etc.. The most convenient substance was tricaine methanesulfonate (MS-222), a popular immobilizer for a variety of cold-blooded vertebrates, including MML's experimental sharks.

Simply stated, a drop of dilute MS-222 solution is added to about 5 ml of seawater sample. After standing at room temperature 2-5 minutes, the immobilized G. breve cells can be easily counted under a microscope, either directly in a shallow-well slide for low counts or by use of a standard blood counting chamber for populations in the range of millions per liter.

This standardized MS-222 immobilization invariably led to considerably higher counts than found by observing free-swimming G. breve, reflecting the distinct advantage of a static microscopic display. Furthermore, the heavier-than-water organisms settled to the focal plane of the flat-bottomed well or surface of the counting chamber grid, thus removing the need for searching the sample in the vertical plane. The individual immobilized organisms also showed a marked tendency to settle flat (dorsal-ventral plane) on the bottom, thereby presenting to the microscopist relatively few instances of confusing lateral views. This counting technique is now being used by a number of governmental laboratories along the Florida west coast to determine intensities of G. breve blooms. Accuracy of this new procedure now has been confirmed in our laboratory thru our recently established capability for electronically counting G. breve.

While initial application of these means for immobilizing G. breve has been to counting procedures, implications are clear in other operations where immobilization and concentration of cells would be advantageous, as in the harvesting of G. breve for purposes of toxin isolation or the changing of medium in high volume cultures.

Aside from general inferences in the literature to the fragile nature of G. breve, we often observed "explosive" disintegrations of organisms even as they were being examined under the microscope. It has been assumed that such occurred in response to external forces generated by handling, evaporation, surface tension, temperature changes, etc. Yet, energetic disruptions were not readily observed with G. breve immobilized by either physical or chemical means. It must then be questioned whether external influences are truly responsible. Could it be instead that these disintegrations are organism-initiated and perhaps serve some useful purpose in the life cycle of G. breve?

Phytoplankton Ecology. The causative phytoplankter of Florida red tide, Gymnodinium breve, has been the object of numerous laboratory studies spanning several decades. Yet, the complex mechanisms that trigger a red tide bloom have remained elusive in spite of considerable intensive research on nutrient requirements for optimum growth of this organism. Dr. Larry Freeberg has now established at MML a capability for comprehensive ecological study of the phytoplankton community in relation to the phenomenon of red tide in Florida waters. In putting this capability to use, Freeberg's current objectives include:

1. Further isolations and identifications of major components of the marine phytoplankton community along the coast of Sarasota, Florida.
2. Studies on variations in dominant members of the phytoplankton community in relation to the dynamic environment; i.e., temperature, salinity, various nutrient chemicals, and possibly sewage outfall.
3. Examining the feasibility of influencing the community in a manner that would maintain a balance of its members, thus inhibiting the imbalance that promotes a G. breve bloom.

Space technology is being brought to bear increasingly through joint studies between MML, the Marine Research Laboratory of the Florida Department of Natural Resources, and the National Aeronautics and Space Administration (NASA). MML, in June 1975, joined with the Marine Research Laboratory of the Florida Department of Natural Resources in a program of seawater sampling and analysis (biological and chemical) designed to produce the surface truthing required for

NASA's development of suitable remote sensors. Limited financial support for these field studies at MML was provided initially by the Florida Department of Natural Resources and is currently supplied by NASA.

Surface and bottom seawater samples are collected at various distances up to 40 miles (occasionally 85 miles) offshore a minimum of twice a month. Six "in situ" parameters are determined for various depths at each sampling station, i.e., depth, temperature, conductivity (salinity), dissolved oxygen, pH, and oxidation/reduction potential. The samples are microscopically examined for the presence of G. breve and the identification of major phytoplankton species. After filtration to remove particulate matter, the samples are chemically analyzed by MML chemist Michael Heyl for major nutrients as well as selected trace metals. Using our refined seawater bioassay techniques, selected water samples are systematically tested for growth potential. Samplings are carefully coordinated with overflights of the area by NASA high altitude (U-2) aircraft and/or orbiting satellites bearing a variety of instrumentation for measuring spectral characteristics of the sea surface. These studies are now an integral part of a continuing joint, contractual study with NASA on surface-truthing biological and chemical factors in suspected association with incipient red tide in Florida waters.

Particularly valuable imagery was obtained in the early months of 1976, utilizing the LANDSAT-1 satellite and an ocean color scanner (OCS) aboard a high altitude U-2 aircraft. High water clarity and the absence of major phytoplankton blooms during that period allowed scientists at NASA's Goddard Space Flight Center to develop a much needed method for identification of nearshore bottom topography.

During routine sampling by MML on 22 September 1976, an elevation in the background count of G. breve was found ten miles offshore from Venice. In cooperation with FDNR, the area from Boca Grande to Tampa was closely monitored in anticipation of a red tide. G. breve populations exceeded the fish-killing (red tide) concentration by September 30, in an area approximately ten miles offshore reaching from Longboat Key to Venice. The first fish kill reported was on 5 October 1976, located approximately five miles off Englewood. By 7 October 1976, G. breve was found in the bays of Sarasota County, and FDNR closed the inland waters for commercial shellfishing the following day.

At the request of NASA's Goddard Space Flight Center, extensive water sampling was conducted on 19 October 1976 in support of simultaneous overflights of the red tide bloom area by a U-2 high altitude aircraft and a LANDSAT-1 satellite. Twenty-five samples were obtained within a 32 square mile area. G. breve enumeration indicated populations from near background counts to approximately five times fish-killing concentrations occurring within one mile of each other (a difference of three orders of magnitude).

Subsequent repetitive cold fronts and associated northerly winds soon acted to move the bloom area far southward from the Sarasota area, beyond the range of meaningful sampling by MML.

Recent acquisition of infrared satellite data from NOAA-Miami has enabled tracking of penetration by the Loop Current into the eastern Gulf of Mexico. Recent data have shown the first half of 1977 to be a year of extended northerly penetration by the current in the late winter and again in the spring. This dynamic current has caused oceanic-type water to be circulated up onto the continental shelf to the point of approaching some coastal regions. Chemical analyses of water samples and microscopic inspections of the flora have helped to verify indications of highly dynamic water on the shelf region of Florida's west coast.

Observations by Freeberg have commenced on confluence of local bay waters and the Gulf of Mexico, in that regions of mixing are being photographed periodically from relatively low altitude aircraft. Collection of baseline data commenced by photographing at 3000 feet the Sarasota shoreline from Stump Pass northward to New Pass, utilizing a variety of film types (i.e., black and white, color, and infrared).

Efforts are well under way by Freeberg towards developing a working collection of unialgal bacteria-free marine phytoplankters. It was first necessary to evaluate a variety of defined artificial seawater and enriched seawater media in seeking a general purpose medium capable of maintaining good laboratory growth of G. breve, as well as a wide variety of other marine phytoplankters. Although further refinement of various media will continue, a modification of Wilson's NH-15 medium is presently the MML standard artificial seawater medium. Additionally, an enriched seawater medium of our own design has been developed and designated as M-1. Cultures of G. breve were obtained from a number of other laboratories, not any of which were found to be unialgal bacteria-free cultures. Development of a pure culture of G. breve remains a matter of high priority at MML, along with similar preparations of other local dominant or bloom-potential phytoplankton species. Confirmation of an axenic culture of G. breve (1976 isolate) by Freeberg now appears close at hand, as indicated by continued favorable results of sterility tests. Establishment of this working collection of unialgal bacteria-free cultures is considered essential to subsequent studies on interrelationships of G. breve with other members of the phytoplankton community.

Further verifications of Freeberg's identifications of algal species in the MML culture collection have been requested of Texas A&M University, Florida State University, and the Florida Department of Natural Resources, Marine Research Laboratory. Although this is a time consuming process, progress is being made.

In determining the changing potential of local Gulf waters for supporting growth of G. breve, samples, regularly collected at sea off Sarasota, are inoculated by Freeberg with G. breve, and the growth, or lack of it, is monitored. The three objectives of such bioassays are as follows: (a) a short-term indicator of the probability of a G. breve bloom associated with optimum water chemistry; (b) nutrient enrichment studies that may indicate which chemical factors are lacking for optimum conditions; and (c) evaluation of standard chemical parameters in relation to G. breve blooms whether a bloom actually develops or not, i.e., "in situ" physical factors may inhibit a bloom.

Much of Freeberg's current research is predicated on the hypothesis that monospecific phytoplankton blooms, such as red tides, are biochemically regulated by concurrent and/or prior populations of other phytoplankters. That is, the growth of one species can be either dramatically enhanced or suppressed by waterborne chemicals produced by other species. Such metabolites are considered to "biochemically condition" natural waters and are therefore important in determining species composition and succession. Bioassays are in progress using numerous species of local algae in media that had been preconditioned, i.e., previously utilized for growing other species of phytoplankton including G. breve. In the case of medium conditioned by prior culturing of G. breve, reduced suitability for growth was observed with 9 selected local diatoms and 11 flagellates. Complete inhibition of growth was seen with two other local dinoflagellates, although G. breve did not appear to inhibit its own growth. A chelate-free medium has now been developed that will support excellent growth of G. breve and other local algal species. This specialized medium was needed for more effective screening of local algal species in regard to biochemical interrelationships.

Freeberg presented a report on MML's current studies to a meeting of Florida's AD HOC COUNCIL FOR RED TIDE RESEARCH in Tallahassee on 18 February 1977. In its subsequent report to the Florida Legislature, the Council suggested the following as its first two priority objectives to be pursued during forthcoming red tide research in Florida:

1. "MML should continue its systematic sampling of offshore waters to examine in as great a detail as possible the organismic and chemical characteristics of the water masses temporally occupying the west Florida Shelf off Sarasota."
2. "MML should seek appropriate support to characterize the red tide toxin(s) so that a simpler, more rapid method than the current mouse bioassay could be developed for detecting toxicity levels in sea water."



Toxin Chemistry. A pilot program was recently initiated by Michael Heyl (MML chemist) for development of a much needed means for a relatively simple, direct chemical determination of G. breve toxin(s) in sea water. Mass cultures of G. breve needed to supply toxin for this project have been established by Freeberg and are continuing well with the new chelate-free medium. Preliminary evaluations of various extraction methods have been completed, and techniques for separation of the various toxins are presently under development. Efforts to detect G. breve toxin using gas chromatography have clearly indicated the need for flame ionization capabilities. The necessary equipment and detector for flame ionization have been purchased and will be evaluated soon.

Data Analyses. Dr. H. David Baldrige has developed convincing evidence for a strong relationship between occurrence of red tide and certain standard oceanographic measurements. Recognizable patterns and rates of change of sea temperatures during the warming period of the spring have been strongly related to later occurrences of major red tides. Aside from the implied increase in knowledge of cause-and-effect, there is inherent in these observations real potential for a predictive technique. Reliable prediction of red tide is absolutely essential to any hopes for control and/or prevention. Warning, with needed lead time, would also be available to public agencies charged, both financially and physically, with countering effects of red tides (i.e., the removal of dead fish) and control of hazards to human health. Presentations of these findings were very favorably received by marine science experts at professional meetings held in Sarasota (October 1974) and Boston (November 1974). A technical paper was published in the Proceedings of the International Conference on Toxic Dinoflagellate Blooms conducted in Boston (November 1974) by the Massachusetts Science and Technology Foundation in association with the Massachusetts Institute of Technology.

Earlier workers generally have attempted to correlate onset of red tide with measured quantities or concentrations of suspected chemical and physical determinants. Blooms have been considered largely the result of random causative perturbations, principally nutritive, in the environment. In contrast, Baldrige envisions red tide as essentially of kinetic origin with its appearance resulting from periodic shifts in rates of a complex interplay of highly competitive chemical and physical processes. It then reasonably follows that dinoflagellate blooms might be highly relatable to first, and possibly second, differentials with respect to time of chemical and physical parameters where correlations have been found to be insignificant in terms of absolute values. For example, rate of change of temperature would more likely be a governing influence on red tide than actual measured degrees.

Additionally, patterns of change in environmental parameters are considered to be equally important as rates of change. Thus, seasonal variations in measured values of chemical and physical factors establish after a time a pattern of change taken as average or normal for that particular region of water. Progressions thru the ranges in values of the various parameters are made at rates resulting from a complex combination of influences. Marine life prospering over long periods of time in such an area would then be those forms capable of accepting normal endemic variations in vital influences, both as to patterns of change and rates of change.

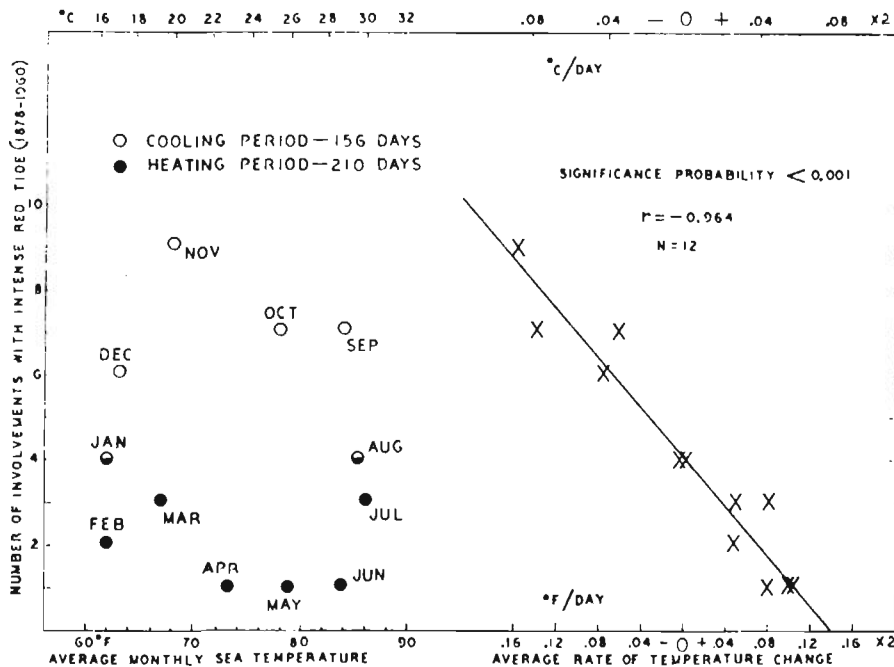
Simply stated, Baldrige's hypothesis is as follows: In regions where red tides periodically occur, the probability of blooms reaching major proportions would be higher when certain conditioning factors more closely follow long-term average patterns and/or rates of change. Once requirements have been met for disposition towards red tide, the actual timing of the occurrence would then depend upon short-range triggering influences such as nutrient availability, competitor pressure, and/or optimum physical conditions.

Temperature was deliberately taken as the parameter of choice for testing Baldrige's hypothesis because of its fundamental role in the kinetics of chemical, physical, and biological processes in general and its recognized influence upon phytoplankton production in the sea. Blooms of G. breve have been observed in Florida waters over a temperature range of 15-33° C, but these organisms do not thrive at the temperature extremes nor when subjected to abnormally high rates of cooling. No previous relationships have been developed between onset of red tide and temperatures within this range, which covers essentially the full seasonal variation along the Tampa Bay region of Florida.

Intense blooms of G. breve appear strongly related to rate of temperature change although rectilinearly unrelated to actual degrees of temperature. All 12 months of the calendar year have been associated with Florida red tides with varying frequencies. The cyclic relationship on the left in Fig. 8 was obtained by plotting (a), the number of involvements of each month of the year with intense red tide in Florida waters during the period 1878-1960 (date courtesy of Dr. Dean Martin, University of South Florida) against (b), the corresponding average sea temperature estimated for each month. Approximate symmetry of the cyclic plot about a mid-range value of approximately 75° F (24° C) indicates minimal dependence of incidence of major red tide upon temperature within the range of occurrence in Florida waters, i.e., about 59-91° F (15-33° C). On the other hand, the shading of the points indicates that the cooling part of the thermal cycle (August thru January) has seen far more intense toxic episodes than the general period of warming (February thru July). This is in spite of the fact that the heating period is almost 40 percent longer than the cooling period.

Additionally, regression (linear plot on the right in Fig. 8) of monthly red tide incidence upon estimated rate of temperature change shows a strikingly intense negative correlation connoting a significance probability of less than 0.001.

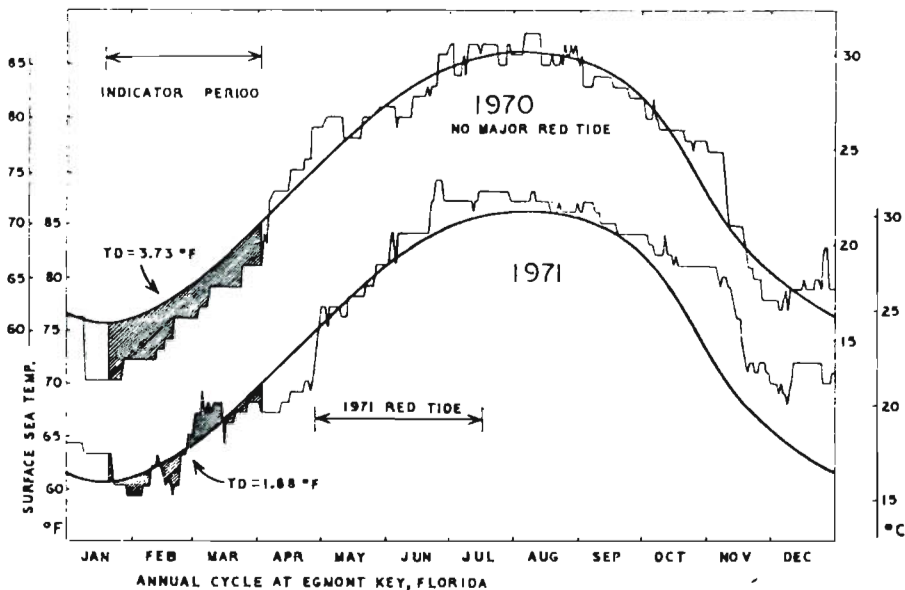
FIGURE 8. Monthly Occurrences of Intense Red Tide in Florida Waters as Related to Sea Temperatures and Rates of Temperature Change.



Baldridge's data analyses have isolated an easily recognized pattern of sea temperatures that has preceded by varying intervals of time every single one of the six major red tides that have occurred along the central west coast of Florida since 1956. Daily surface sea temperatures (recorded by the U.S. Weather Service at Egmont Key, Florida at the mouth of Tampa Bay) were plotted against the background of a smooth curve representing the long-term average yearly water temperature cycle (Fig. 9). The departure of each relatively irregular yearly plot from the average smooth curve was found to be far greater during the cooler period between the autumnal and vernal equinoxes than during the warmer months of the year. Even cursory subjective examination of a series of such annual plots beginning with 1957 (earlier Weather Service records were incomplete) shows that departures from the average curve vary considerably from year to year and that occasionally a low temperature cycle appears wherein the magnitude of departure from average is strikingly low in the context of adjacent annual

cycles. Interest increased when it was realized that major fish-killing blooms of *G. breve* occurred during the "red tide season" that followed each and every occurrence of relatively minimal departure of temperatures from the long-term average.

FIGURE 9. Typical Patterns of Daily Mean Surface Sea Temperatures (Egmont Key, Florida) in Comparison to the Average Annual Cycle. The data were treated in ° F, as actually recorded by the U.S. Weather Bureau. Darkened areas signify deviations of temperature from the average cycle during the indicator period, 19 January - 2 April. Magnitudes of the deviations were calculated in terms of "temperature departure (TD)", as defined in the text. Note the relatively minor variations in 1971 compared to the previous year. Also, as seen on other occasions, the major red tide of 1971 followed a lengthy period of minimal temperature change.



Baldrige devised a modification of standard deviation, the "temperature departure (TD)", to quantify variations in patterns of daily water temperatures from the smooth average curve of Fig. 9. Temperature departure measures magnitude of deviation from a normal temperature curve and does not differentiate between directions of deviation, i.e., warmer or cooler. The TD is given by the formula,

$$[ \sum (T - T_a)^2 / (N-1) ]^{1/2} ,$$

where  $T$  is the measured daily mean water temperature,  $T_a$  is the long-term average temperature for that day (taken from the smooth

mean curve in Fig. 9), and N is the number of days in the indicator period (74, except for one additional in leap years). Values for TD generally were in the range 1.9-6.5° F (1.1-3.6° C), with zero indicating no deviation at all in temperature pattern from that of the long-term average during the indicator period 19 January - 2 April.

The dashed curve A in Figure 10 shows quantitative variations in the yearly temperature departure (TD) from the long-term average pattern of warming during the suspected critical period of 19 January - 2 April. Relative low temperature departures (in the context of preceding and following years) are indicated by sharp minima in curve A for the years 1957, 1959, 1963, 1967, 1971, and 1973. It was during these years, and only these, that major red tides occurred in the vicinity of Egmont Key during the intervening period.

There is no predictive value in recognition of minimum points in curve A, for establishing of such a minimum for a particular year requires measurements made during the following year. Curve B, of Figure 10, recognizes the occurrence of a rapid drop in TD value immediately preceding a relatively minimum value of TD. For example, the sharp peak in curve B for 1959 results from the rapid drop, i.e.,  $\Delta$ TD, in the TD value for 1959 as compared to that for 1958. Peaks in curve B also are associated in time with each and every one of the major outbreaks of red tide in the period of concern. Furthermore, all of the red tide years were characterized by TD values that were lower than the previous year by more than 0.75° F (that is,  $\Delta$ TD greater than 0.75° F). Here then was the starting point for development of a predictive technique based on simple standard oceanographic measurements.

The "predictive" pattern was seen again during the early months of 1975. The sharp drop in TD value for 1975, clearly evidenced in curve A, produced a  $\Delta$ TD value of 1.3° F, well above the 0.75° F considered indicative of red tide. These measurements strongly suggested that 1975 would be characterized by a relatively minimum temperature departure, i.e., lower than both 1974 and 1976. On this basis, we reasoned that major occurrence of red tide during the period 2 April 1975 - 2 April 1976 would be consistent with statistical considerations going back 20 years.

The predicted bloom did not occur. Furthermore, the TD value subsequently calculated for 1976 was well below that for 1975, clearly showing 1975 not to be a year of relatively minimal temperature departure as expected from the high 1975  $\Delta$ TD value (see curve A in Fig. 10). However, a relatively high TD value recently calculated for 1977 (not shown in Fig. 10) produced another sharp minimum in the TD plot at 1976, a fact that was consistent with the appearance of an intense, fish-killing G. breve bloom in the vicinity of Sarasota-Venice in September and October of 1976. Before this bloom could become more

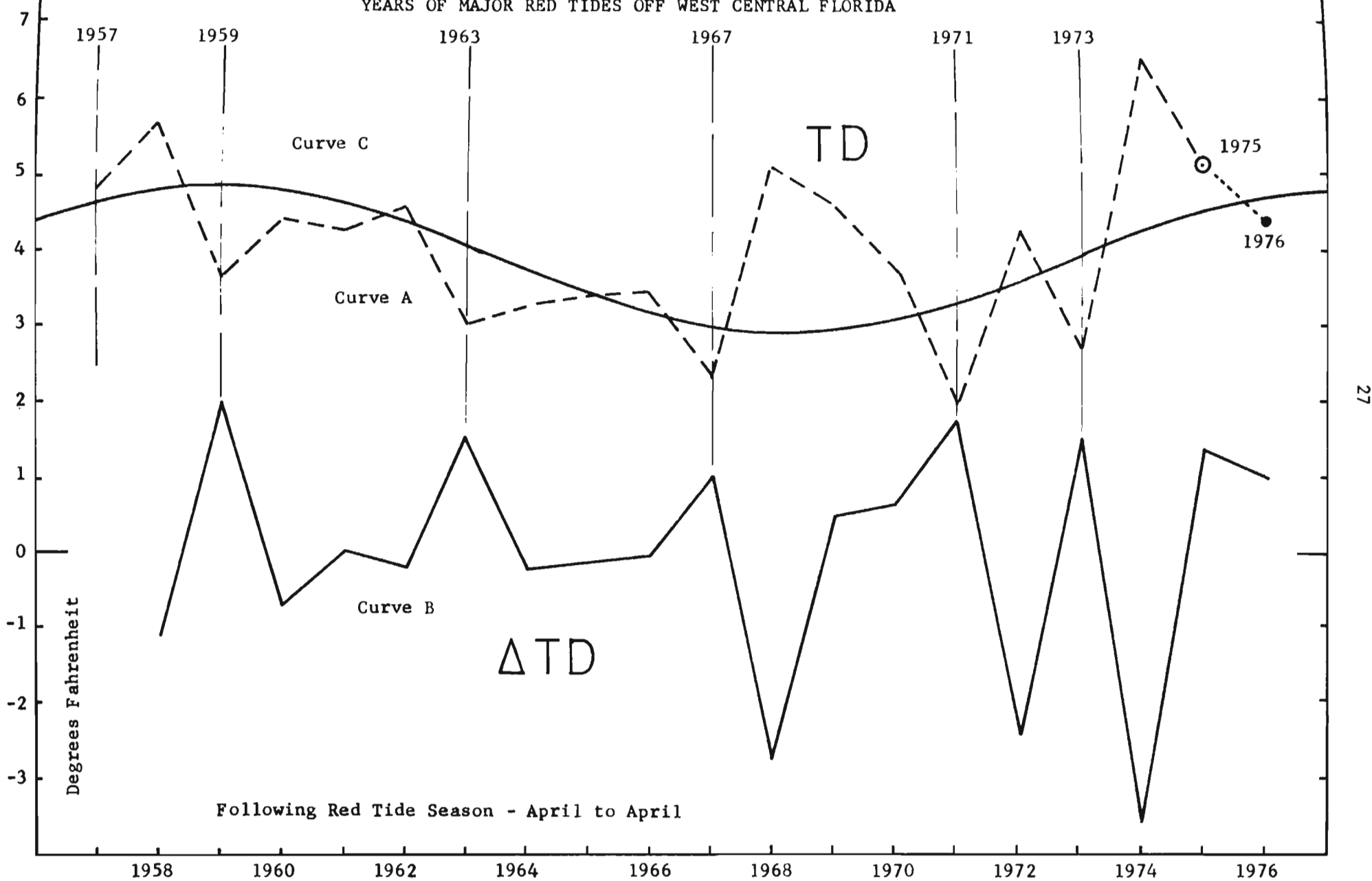


Figure 10. Temperature Departures(TD) and Values of  $\Delta TD$ (TD of Previous Year Minus that of Subject Year) during Indicator Period of 19 January - 2 April and Relationships to Occurrences of Red Tide off West Central Florida.

widespread in the Tampa Bay area, it was moved far southward under the influence of prolonged northerly winds and currents.

As a consequence of the erroneous prediction of a significant red tide between April 1975 and April 1976,  $\Delta TD$  has been weakened as a tool for predicting both minimal values of TD and occurrence of major red tide (but only slightly, for it still checks out 19 times in 20 opportunities, i.e., seven alignments with red tide over a 20-year period with only one false positive). It should be readily apparent, however, that possible weakness of  $\Delta TD$  as a predictive tool does not in any way detract from Baldrige's basic observation that occurrences of Florida red tide coincide on a time scale with sea temperature patterns that can be easily recognized both subjectively and objectively. Nevertheless, there remains a pressing need for developing from these data a prior indication of temperature pattern development that could be used for completely reliable red tide prediction.

The developing link between Florida red tide and water temperature patterns is probably only a temperature-handle on some other causatively related parameter. Water temperature measurements taken at a fixed location, such as Egmont Key, very likely evidence water masses of different temperatures as they move into and out of the area.

Consider that wide surface temperature variations might in reality reflect major changes in movements of water currents along Florida's west coast; strong currents from the north dropping the temperature below normal, with movements from the south causing temperatures to rise abnormally. Such an interplay of strong cross-currents could conceivably flush from coastal areas (in the vicinity of passes and embayments) certain vital nutrients and/or trace elements that might otherwise accumulate and be available to G. breve. Consider further that some critical part of this organism's as yet largely undefined life cycle might be occurring during the early months when the sea is just beginning its warming period. Thus, an abnormal pattern of water temperature could mean that unusual movements of currents so stress the G. breve "seed population" in the early spring that it is incapable of supporting a later bloom of red tide proportions.

There are growing indications that optimum conditions for Florida red tide might be associated with tidal activity. For example, curve A in Figure 10 appears suspiciously to follow the 18.6-year tidal cycle represented by the sinusoidal curve C.

If the link between spring temperature patterns and later occurrence of red tide is through tidal activity, another possible model is readily apparent. Correlations have also been developed by Baldrige between surface sea temperatures and certain characteristics of Florida's



various central gulfcoast tidal cycles. A particular pattern of sea temperatures in the spring could simply be the hallmark of a particular form of tidal activity. And, tidal activity later in the year is surely related in many ways to activity in the spring, as evidenced by the availability and value of tide tables. The "seed population" of G. breve would then not have to be affected directly in the spring. It could simply be that there is a high degree of predetermination in the form of tidal activity (and associated nutrient and/or inhibitor availability) that might be either favorable for growth of G. breve or unfavorable for its competitors.

Besides tidal activity, Baldrige, in attempting to isolate true causatively related environmental factors with which the "temperature-handle" might be associated, has examined such parameters as air temperature, barometric pressure, wind direction and speed, cloud cover and availability of sunlight, rainfall patterns, etc.

As would be expected if sea temperature patterns are reflective of movements of surface water masses of varying temperatures, Baldrige has now developed relationships between red tide occurrence and surface wind vectors. Preliminary calculations show that the resultants (i.e., vector sums) of surface winds at the Tampa Weather Station, during each 19 January - 2 April period, are essentially east-west oriented in years characterized by red tide and north-south oriented in bloom-free years. This observation is highly consistent with the above suggested possible influence of an interplay of northerly and southerly springtime currents in the subsequent development of conditions either favoring or discouraging later G. breve blooms.

Associated Studies. Almost \$60,000 (including \$25,000 from the Florida Legislature, 1974-75) of MML funding for red tide research over the past five years has gone to support various phases of our program conducted at the University of South Florida. Graduate students, under the direction of Dr. Harold Humm, have studied balances of temperature and light required for optimum growth of G. breve, the causative organism of Florida red tide. In essence, cultures of G. breve were located at known positions in a controlled temperature gradient, while at the same time being exposed to graduations in quality and intensity of the light that is required for their photosynthetic processes. Balances of light and thermal conditions associated with optimum growth characteristics were then related to field conditions giving rise to natural red tide blooms. Chemical analyses of our water samples were also conducted at USF under Dr. Humm's direction, with partial defrayment of costs provided by MML.

About half of MML funds provided to USF were utilized by Dr. Dean Martin in his mathematical treatments of our water sampling data and studies on isolation and chemical characterization of G. breve toxin. He also has been concerned with the possible utilization of man-made

and natural surfactants as agents for control of red tide blooms, especially in the very early stages of their development. Martin is also considering naturally occurring organisms (competitors, inhibitors, etc.) for limiting the growth of G. breve and thereby suppressing population levels to non-bloom proportions.

### PUBLIC RELATIONS

Red tide, because of its profound economic repercussions, has been a very delicate public relations tightrope for MML. On one hand, MML is a privately funded research laboratory, and thus for research support depends heavily on contributions from individuals and grants from foundations. Maintenance of such support for red tide research, in turn, required a high public visibility of ongoing studies, even to the point of release and discussion of MML scientific observations, hypotheses, theories, etc. at stages of development usually considered by prudent scientists as too tentative for presentation beyond the laboratory. On the other hand, the specter of severe financial losses frequently led influential, and at times highly vociferous, members of the affected economic community to respond with negative vigor whenever mention of MML's Red Tide Research Program was made in the local news media.

Then there were those times, primarily late in periods of prolonged and intense red tide, when naive impatience compounded by frustration led groups of businessmen to respond to schemes for immediate, simple solutions to their economic plight. Such particularly was the case, on 7 June 1974, when public confidence in MML's Red Tide Research Program was shaken by an uncontested presentation to the Sarasota Chamber of Commerce by a group calling itself the Suncoast Action Committee on Red Tide (SACORT). Briefly, the spokesman for SACORT contended that control of red tide was clearly within the present state of the art. Incipient blooms, detected by remote imagery generated by space satellites, would be quenched by inoculating the "infected" volume of water with microscopic predators that are selective for the red tide organism, G. breve. MML scientists were not given the opportunity to evidence the fact that no such state of the art existed. It is to the credit of the Selby Foundation that such openly expressed efforts to divert funds from MML's scientific program met with no success.

Fortunately for MML, there resulted from this 1974 Chamber of Commerce meeting an intensification of earlier described collaborative studies by MML, NASA, and FDNR (Marine Research Laboratory, St. Petersburg) on the very difficult problem of detecting red tide from high altitude aircraft and/or space satellites.

There also rose from this June 1974 Sarasota Chamber of Commerce meeting a strongly expressed desire by local business leaders to bring recognized scientific authorities together for the purpose of preparing an objective, comprehensive statement on the present state of the art of red tide research, with particular attention to immediate prospects for control and/or prevention. With the technical assistance of many (including MML) and financial support provided by the Sarasota County Commission, a Florida Red Tide Conference was held in Sarasota, 10-12 October 1974, under the sponsorship of the then newly created (by the Florida Legislature) Ad Hoc Council for Red Tide Research. Of the 20 technical papers presented, four were authored by members of the MML staff. Dr. Perry Gilbert, Director of MML, presented an overview of the collaborative MML-USF Red Tide Research Program. Dr. Larry Freeberg spoke on "Ecology of the Phytoplankton Community in Relation to Blooms of G. breve". A paper on the use of sea "Temperature Patterns as Early Indicators of Impending Red Tide in Florida Waters" was presented by Dr. H. David Baldrige. Claire Gilbert discussed her paper (coauthored with Eugene Habas) on "A Preliminary Investigation of the Economic Effects of the 1973-1974 Red Tide."

The hazard of open public discussion of preliminary scientific findings on such a volatile issue as red tide was clearly seen in the months following Baldrige's discussion of a possible prediction technique at the October 1974 Sarasota Red Tide Conference. At that stage of Baldrige's studies, it was scientifically sound to conclude that occurrence of red tide in the fall, winter, or early spring (1975-76) would be consistent with statistical considerations going back almost 20 years. Because of the sensational nature of this observation, repeated inquiries as to the day-to-day status of calculations were made by local reporters, resulting in periodic restatement of Baldrige's suspicions in the area press. Severely compounding matters, a local free-lance writer prepared a rather sensational article, including a firm statement of red tide prediction, which unfortunately appeared as the cover story on the Travel Section of a Sunday edition of the New York Times, 24 August 1975. Capping this was an emblazoned article in the Sarasota Herald Tribune on 28 October 1975 stating not only a firm prediction, but also calling for a severe red tide specifically the following month. Possibly very little was accomplished by the comparatively limited space, 13 column inches, given on 5 November 1975 to Baldrige's attempt to clarify his stand and to point out that there are no such absolutes in the science of statistics. The predicted red tide did not develop within the time span specified. Baldrige took that fact into account and modified his calculations accordingly. Consequently, MML science advanced as a result of the non-occurrence of a red tide that had been expected on the basis of early interpretations of a developing prediction technique - but not without a price in terms of a blow to good public relations with the local economic community.

It is regretted that attempts to keep our financial supporters (and the general public) informed on the status of our research on red tide have been at times interpreted in ways not of our intent and that might have been detrimental to certain segments of the local economic community. In spite of this hazard, we fully recognized our responsibility to the many supporters of MML in terms of making our research findings readily available to them.

To this end over the past five years, members of the MML Red Tide Research Program have made countless presentations to public gatherings, service clubs, governmental bodies, scientific societies, etc.; in person, by radio, television, and newspapers. MML cooperated with the United States Navy on a documentary film dealing with world-wide concern for various forms of red tide, including the Florida fish-killing G. breve bloom. Up-to-date scientific findings were regularly discussed at briefings periodically held for supporting members of MML, and general field data (such as organism counts during blooms), then as now, were made available to all local governmental agencies.

Direct response to needs of the general public was evidenced during the prolonged 1973-74 red tide by assignment, on essentially a full time basis, of an MML staff member to the purpose of providing enlightened answers to the many hundreds of telephone inquiries.

#### PLANS FOR THE FUTURE

For the fourth consecutive year, the Florida Legislature has appropriated funds (\$25,000) in partial support of red tide research at MML. Additionally, continuation of the collaborative MML-NASA red tide surface truthing program has been assured through 30 September 1978, by recent extension of our current contract at a funding rate of about \$22,000 per year. Furthermore, NASA has expressed a desire to develop with MML a data base for remote imagery studies over the next three to five years.

Dr. Larry Freeberg will continue development of his program of phytoplankton ecology, especially in the area of environmental factors directly associated with the ability of natural seawaters to support bloom-level populations of G. breve. Experimental and field work remain geared primarily to following vital signs in the physics and chemistry of nearby Gulf waters in anticipation of the inevitable next major red tide. Emphasis will include:

1. Species isolation, water sampling, sample inspection, chemical analysis of samples and development of surface truthing data in collaboration with NASA and the Florida Department of Natural Resources.

2. Screening of all algal species in pure culture for potential interrelationships, employing the newly developed chelate-free medium. Definitive interactions with G. breve will be pursued using mixed culture techniques. Additional funding providing for expansion of this portion of the program has been requested of the National Science Foundation and the National Institute of Environmental Health.
3. Further delineation of standard growth characteristics of all species in axenic culture.
4. Periodically photographing from low altitude the bay/gulf mixing zone in the region of Sarasota, particularly at times when highly turbid water flushes from the bays in response to periods of heavy rainfall.

MML chemist Michael Heyl will intensify development of more effective means for rapid, direct detection and measurement of G. breve toxin in seawater. In addition to chemical and instrumental techniques, hypersensitive biological systems will be investigated as a means for determining the extremely low concentrations of toxin in sublethal blooms of G. breve.

The MML economic research team of Eugene Habas and Claire Gilbert stands ready to evaluate any and all forms of economic blows dealt to Florida commercial interests by red tide. One study under consideration has to do with reported adverse effects engendered by newspaper and television publicity not directly associated with an actual on-going outbreak.

In independent associated studies, Dr. H. David Baldrige will continue investigating long term patterns of oceanographic and meteorological factors in relation to occurrence of Florida red tide. Primary objectives include:

1. further study of the relationship between patterns of changing sea temperatures and outbreaks of red tide, including indications of bloom-triggering by aberrant temperature changes,
2. examination of other oceanographic and climatological parameters to gain insight into direct cause-and-effect relationships with red tide,
3. recognition of implications in data analyses pertaining to possible methods for controlling red tide in Florida waters.

Firm establishment of a highly suspected controlling link between climatological and/or oceanographic factors and occurrence of major red tide would permit the important matter of control to be viewed in proper perspective. Accurate prediction of red tide would be a very worthwhile,

practical as well as scientific, spinoff of such considerations. Valuable planning use could be made of predictive information by municipalities concerned with sanitation and pollution control and especially by public and private health agencies. Beach-oriented tourist industries would benefit, for a reliable predictive technique would equally identify seasons of expected freedom from red tide. Researchers could schedule more effective and efficient field studies. Any practical control of red tide would surely require detection of blooms in very early developing stages - more likely accomplished if the blooms are expected thru prediction.

### ACKNOWLEDGEMENTS

Our sincere gratitude goes to three groups of individuals:

1. those who had faith in our scientific stature to the point of providing us with the financial means for establishing and conducting a program for red tide research at MML,
2. our associates, both scientific and lay, who freely shared with us their moral support, wisdom, and experiences from past and present associations with red tide research,
3. and, the many members of MML's scientific and administrative staff who, at times under very difficult conditions, carried out all the details that came to fruition in the form of solid research findings and increased knowledge about Florida red tide.

In being specific, there will always be someone of importance overlooked. If this be the case here, it will likely be because they accomplished their assignments efficiently and with little fanfare. Such slights are unintended.

Helen and William Vanderbilt  
 The William G. Selby and Marie Selby Foundation  
 William Coleman  
 Marvin Vorderburg  
 The Florida Legislature  
 Robert Johnson  
 Van Poole  
 The United States Senate  
 Senator Lawton Chiles  
 National Aeronautics and Space Administration  
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 Dr. Jim Mueller

Florida Department of Natural Resources

Edwin Joyce  
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Dr. Harold Humm  
Dr. Dean Martin  
Dr. William Taft  
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Mr. and Mrs. John H. Marshall  
Save Our Bays Association  
Sarasota County Commission  
Dr. Donald G. C. Clark  
Mr. and Mrs. George C. Seward  
Basil S. Turner  
D. W. Brosnan

Concerned Area Citizens:

Jim Neville, Sarasota  
Dante Vezzoli, Sarasota  
Joseph Tucker, Venice  
Fred McCormack, Sarasota and Tallahassee  
Allan Horton, Sarasota  
others too numerous to mention

Boat Owners:

Keith McCulloch of SHARK  
Dr. William Hoffman of LIEBETH  
George Howell of MISS MIM  
Sarasota County Anglers Club  
William Mindlin, President  
Tony Trione (Vice President), of TONI-LOU II

United States Coast Guard:

Headquarters, Seventh Coast Guard District, Miami  
U.S. Coast Guard Air Station, St. Petersburg  
U.S. Coast Guard Light Station, Egmont Key  
U.S. Coast Guard Cutter POINT THATCHER, Sarasota



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Dr. Edward Evans, Microbiologist

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Dr. Larry Freeberg, Biological Oceanographer

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Dr. Perry Gilbert, Director of MML

## APPENDIX A

Draft prepared by:  
Dr. H. D. Baldrige  
Mote Marine Laboratory  
Sarasota, Florida 33581  
(813) 921-6661

Dr. James C. Fletcher  
Administrator, NASA  
400 Maryland Avenue  
Washington, D. C. 20546

Dear Dr. Fletcher:

This is to ask assistance of the National Aeronautics and Space Administration in a matter seriously affecting the economy of Florida and the health and well-being of its citizens.

At irregular and unpredictable intervals, massive blooms of a toxic marine organism in Florida waters give rise to a phenomenon called "red tide". Because of unsightly and unsanitary, malodorous conditions produced by tons of dead fish at the water's edge during major red tides, severe economic stress is placed upon adjacent tourist-oriented communities. Waters of the Gulf of Mexico along the Suncoast of Central Florida have been particularly adversely affected. I have enclosed a recent report from the Mote Marine Laboratory in Sarasota that estimates economic damage at about \$20 million caused by the relatively moderate red tide of 1971. The business interests of the regions from Clearwater to Boca Grande are only now beginning to assess far greater losses incident to the currently waning intense red tide that has plagued the area since early last November.

Of even greater importance, the potential for serious human health problems has now become acutely apparent. Unlike earlier Florida red tides, the present prolonged outbreak has shown scattered reports of human

neurotoxic shellfish poisoning and a greatly increased incidence of respiratory disease in both humans and domestic animals.

If red tide in Florida waters is ever to be controlled, the key will surely lie with early detection. It is here that the National Aeronautics and Space Administration could provide a very valuable service to the people of Florida. I have in mind the use of satellites and aircraft, conventional and unconventional, for the purpose of detecting burgeoning red tide.

A variety of valuable data on remote sensing already has been made available by NASA for use in red tide research programs. Yet, the data have been essentially of a fragmentary nature. It would be very useful to scientists seeking to solve our problem if the various involvements of NASA of relevance to early detection of red tide could be drawn together in a single treatise.

It is for this purpose that the concerned citizens of Florida have asked for a comprehensive report by NASA on the state-of-the-art regarding:

a) capability for observing plankton blooms in general and red tides in particular from satellites, high-flying aircraft such as the U-2, and aircraft at conventional altitudes. Also, the capability for mapping surface sea temperatures and movements of water masses in coastal waters.

b) ground-truth matching with remote imagery from satellites and aircraft involving known plankton blooms (red tides especially), surface sea temperatures, and movements of coastal water masses, with particular emphasis on gulf waters along the central west coast of Florida.

c) listing of offices and individuals (including research objectives) within various NASA installations concerned with observations on physical

and biological oceanographic parameters from satellites and aircraft. Include listing of similarly concerned NASA contractors and abstracts of their research involvements and goals.

d) mechanisms within NASA for making such information readily available to research programs, privately and publicly supported, showing need for such data.

e) potential for affecting design phases of NASA satellite and aircraft missions so as to maximize availability of data of importance to research on red tide in Florida waters.

f) possibility of modifying present NASA-USGS water resources remote imagery missions to cover neritic and marine waters along Florida's west coast.

g) other capabilities of NASA for aiding in early detection and monitoring of red tides in Florida waters.

In addition to this office, please make copies of the report directly available to:

- 1) Mote Marine Laboratory (Attn: Dr. H. D. Baldrige), 9501 Blind Pass Road, Sarasota, Florida 33581
- 2) University of South Florida (3 copies)

University of South Florida  
Department of Marine Science  
Attn: Dr. Harold Humm  
St. Petersburg, Florida 33701

University of South Florida  
Director of Research (Dr. William Taft)  
Tampa, Florida 33620

University of South Florida  
Department of Chemistry (Dr. Dean Martin)  
Tampa, Florida 33620

- 3) Florida Department of Natural Resources  
Bureau of Marine Science and Technology (Attn: E. Joyce)  
Larson Building  
Tallahassee, Florida 32304

- 4) Florida Department of Natural Resources  
Marine Research Laboratory  
100 Eighth Avenue  
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- 5) State University System of Florida Inst. of Oceanography  
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St. Petersburg, Florida 33701
- 6) Florida Coastal Coordinating Council  
Tallahassee, Florida 32304
- 7) Florida Council of 100  
Oceanography Committee  
Post Office Box 2192  
Tampa, Florida 33602

Cooperation in this important matter at your earliest convenience  
would be greatly appreciated.

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(Sen. Lawton Chiles)

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