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THE RED TIDE

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by

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THE RED TIDE

CONTENTS

	Page
Summary	7
1. What Is Red Tide?	9
2. What Causes Red Tide?	9
3. What Are the Effects of Red Tide?	10
4. Recent Outbreaks of Red Tide	12
5. When and Where Is Red Tide Likely to Return?	16
6. What Is the Red Tide Gas?	16
7. Currents and Red Tide	17
8. What Is Being Done About Red Tide?	18
9. Can Red Tide Be Controlled?	24
10. Florida Board of Conservation Publications Emanating from Red Tide Studies	24
Selected Technical References	26

SUMMARY

1. Florida Red Tide is caused by the microscopic organism, *Gymnodinium breve* Davis. Normally present in seawater along the Florida west coast in small concentrations, they may suddenly reproduce at a rapid rate, resulting in astronomically high numbers of individuals. The water then becomes characteristically discolored. The organism produces toxic substances which, during a bloom, are sufficiently potent to kill marine animals.
2. *G. breve* is a very delicate and fastidious organism. Its requirements and optima must be met on precise levels for it to survive and multiply. Temperature, light, stability of surrounding media, organic nutritional substances, and metals must all be at the correct level for blooms to develop.
3. Since 1844, Florida Red Tide has occurred at least 16 times in major proportions. There may have been outbreaks that were unreported due to sparse population in the coastal areas and inadequate communication.
4. When Red Tide appears, a slightly irritating gas may be noticed. It has been suggested that this may have man-made origin but biological evidence indicates the causative factor is the breakdown of the Red Tide organism. The irritant effects of the gas are restricted to the sea or beach areas and are temporary. The slight coughing and other symptoms disappear when Red Tide diminishes.
5. Fishes which are not killed or whose behavior is not noticeably affected by Red Tide are apparently safe for human consumption.
6. Mollusks such as mussels, clams, and oysters that are removed from Red Tide waters must be regarded with suspicion. There is a definite relationship between toxicity in these filter-feeding animals and high concentrations of *G. breve*.
7. Recent studies have indicated that the addition of EDTA (ethylenediamine tetra-acetic acid) and iron to seawater samples containing *G. breve* promotes survival and growth.
8. An extensive sampling program in North and South Florida has revealed that streams entering the Gulf contain high concentrations of iron and humic acids (coffee-colored substances). The latter may assist in making iron and other

metals soluble in seawater just as EDTA does in the laboratory. It is hoped that the present sampling program will provide information on the relationship of land runoff to Red Tide.

9. Financial support for Red Tide investigations for many years was inadequate and undependable. In 1963 the Florida legislature appropriated funds sufficient for a large scale research project. This support was again provided in the 1965 session. As a result of this assistance much has been learned. Scientists of the Board of Conservation have suggested a method of control. Work now is concerned with verifying the practicality of this method.
10. The control suggested involves the construction of dams across major streams of afflicted areas.

THE RED TIDE

by JOHN TORPEY and ROBERT M. INGLE

1. What Is Red Tide?

Red Tide is the popular name given to discoloration of water (fresh and salt) caused by microscopic organisms. Florida Red Tide is caused by one organism, *Gymnodinium breve* Davis, which produces a chemical substance of high toxicity. This toxin acts upon the esterase enzyme systems at motor nerve endings, causing paralysis and often the death of aquatic organisms. On the other hand, when dense populations of non-toxic microorganisms deplete dissolved oxygen, suffocation can bring about widespread mortality.

Red Tides are fairly common throughout the world. Scientists have made observations on them for many years in India, Africa, southern California, Texas, Puget Sound, Peru, Japan, the Island of Luzon, the east coast of Australia, Narragansett Bay, Delaware Bay and many other locations.

2. What Causes Red Tide?

In earlier years, many conflicting theories as to the nature and cause of Red Tides in Florida have appeared in newspaper reports. The causative agent, a previously undescribed microscopic organism, was identified in January, 1947, by scientists working on behalf of the Florida Board of Conservation, and was given the name *Gymnodinium breve* by C. C. Davis. This dinoflagellate is one thousandth of an inch in width and has the general appearance shown in Figure 1. By means of two undulating whips, one trailing behind and one encircling the middle, it spirals through the water. *G. breve* is single celled and has both animal and plant characteristics. Normally it is present in seawater off the west coast of Florida in quantities of less than 1,000 to the quart and in this concentration appears to be harmless. During periods of intense Red Tide, populations may reach 60 million to the quart.

In seeking to find the reason for the great increase of *G. breve* it is first of all necessary to understand its way of living. Since it behaves to some extent like a plant, it requires nutritive substances for its growth. Normally the most important of these are phosphorus and nitrogen. Their concentrations are sufficient to support the number of organisms which usually live in seawater but for rapid multiplication of *G. breve*, additional quantities of these and other nutrients must be present. Also, chelating mechanisms may influence the availability of these nutrients. However, these re-

relationships are not well-known and therefore the nutritional problems have become an important objective of further studies. Large scale water movements and local disturbances in the chemical and physical conditions of the sea are being considered as likely additional factors and are under investigation at present.

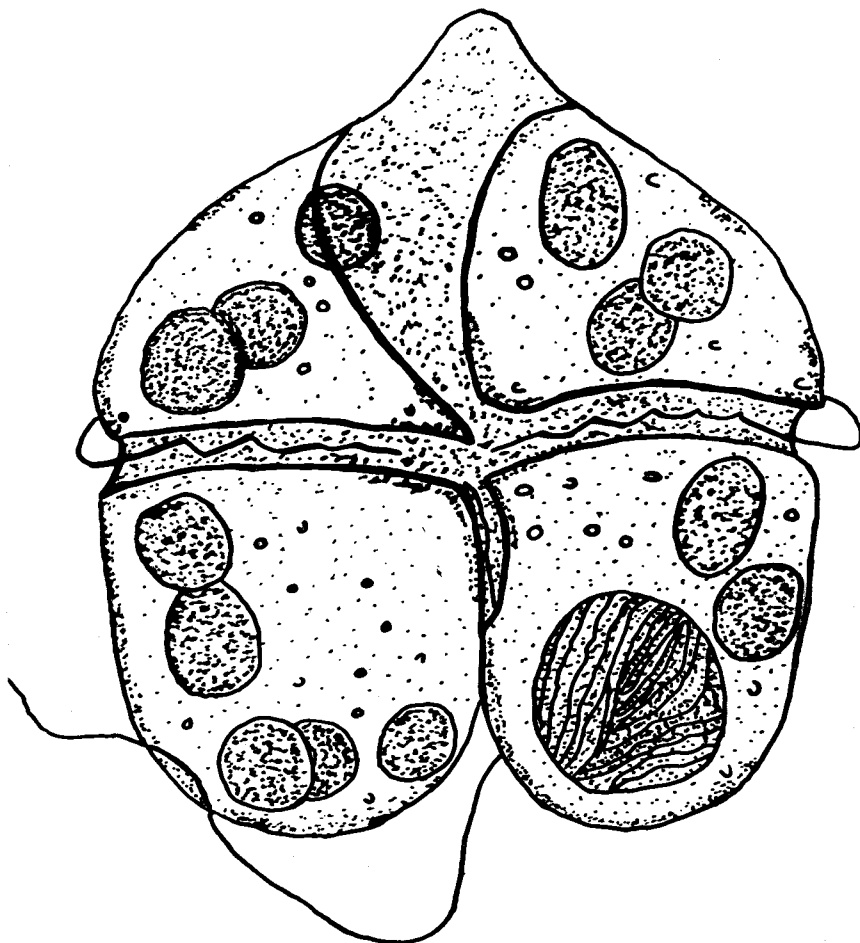


Figure 1. *Gymnodinium breve* Davis, magnified 5000 times.

3. What Are the Effects of Red Tide?

Red Tide first appears as colored patches of water, varying in size. These affected water masses become soupy or cloudy as the numbers of organisms increase. The color of the water progressively changes from light green to a deep amber color, sometimes with a distinct reddish tinge. At the same time, the water becomes more and more viscous or slimy until, when taken up in the hand,

it runs from the fingers in strings like thin syrup. At this stage the greatest mortality of marine life usually occurs. (See Figure 2). As the red color disappears, a scum and patches of debris often remain on the water surface. Other areas of Red Tide may develop elsewhere and the whole cycle could re-establish itself nearby.

If conditions are optimal, there is a possibility that outbreaks may be self-perpetuating. As various marine animals die, they decompose, releasing additional nutrients which may be utilized by

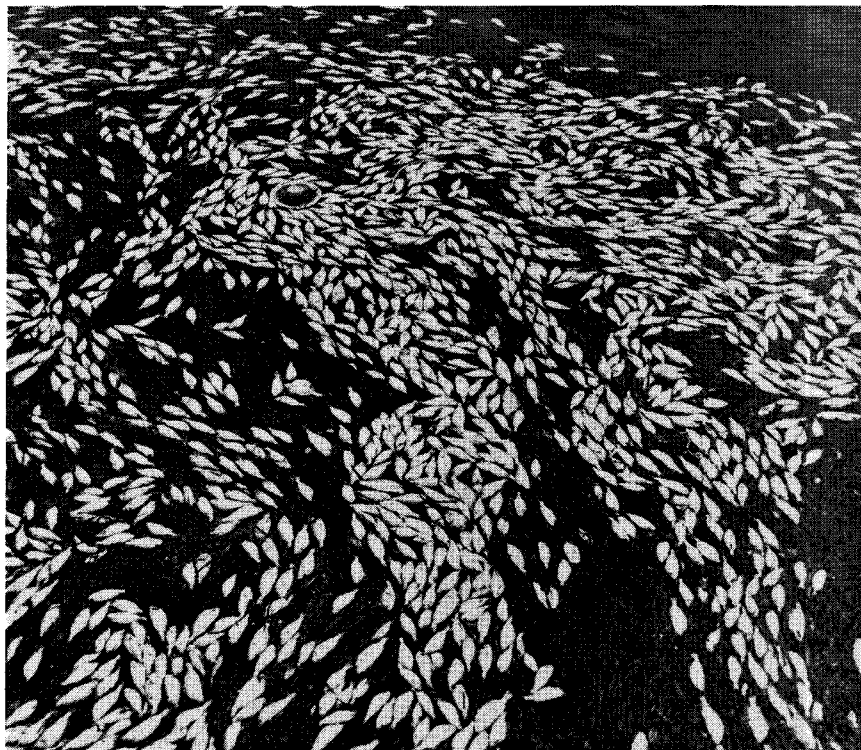


Figure 2. Heavy accumulations of dead fishes marking the edge of a Red Tide near Tampa Bay. Courtesy of St. Petersburg Times.

Red Tide plankton. This "snowballing" effect may greatly increase the extent and toxicity of a Red Tide. Certain organisms such as the alga *Trichodesmium* may be concentrated into small areas by hydrological features, thus making available its nutrient content.

Harmful effects of Red Tide are not confined to fishes. Barnacles, oysters, coquinas, shrimps, crabs, horseshoe crabs, porpoises, and turtles have also been reported killed.

Most inshore species of fish are affected but mackerel, bonito

and other pelagic forms are rarely found. Dead and dying fishes most often noted on the beaches and in the water close to shore have been grunts, porcupine fish, snake-eels, catfish, pinfish, mullet, and batfish. In smaller numbers, but no less striking, are large tarpon, grouper, and jewfish.

Lines or drifts of closely packed fishes may extend for miles and move slowly towards shore. Near Fort Myers Beach, in January, 1947, a ten yard wide "windrow" stretched along the beach for nearly five miles, with as many as one hundred and seventy fishes to the foot. On Captiva Island, one home owner buried approximately 60,000 fishes in a two hundred foot stretch of beach.

Rotting carcasses of marine animals killed by Red Tide create an unpleasantness along affected shores. This is often sufficiently noxious to result in diminished tourism, causing financial distress to many normally popular and prosperous centers.

Studies of fish production do not indicate that Red Tides significantly reduce commercial landings. In contrast, certain types of sport fishing are seriously affected. Party boat captains and sport fishermen all agree that certain nearshore fishing is harmed, including that for grouper and snapper. As a result, operating expenses of party boats have been increased by the greater distances they must travel. In time these affected areas become repopulated and reef fishing close to shore may then be resumed. There is also evidence that Red Tides may temporarily deplete the bait fish in some areas.

It should be pointed out that fishes not actually killed during a Red Tide appear to be safe for consumption. While sick or dying fishes may be questionable in their toxicity to human beings, those which escape death have apparently warded off the toxin. In many instances people have eaten fishes from Red Tide areas almost immediately after an outbreak and have not been affected. However, a relationship to the production of poisons is found in that shellfish which filter Red Tide organisms frequently accumulate enough of the harmful substances that they may become poisonous to human beings. Thus, blooms of this type of organism have so infected edible mollusks in various parts of the world that a great many human deaths have resulted.

4. Recent Outbreaks of Red Tide

Red Tide appeared in November, 1946, on the Gulf Coast of southern Florida, near Naples, after a 14 year period during which it was not recorded. Fishermen reported large numbers of dead and dying fishes floating in the vicinity and as far as 10 miles offshore. The deaths of fishes increased and the Red Tide moved northward. By the end of January, 1947, bays and beaches of Fort

Myers, Sanibel Island and neighboring areas were strewn with millions of dead fishes. The problem of disposal was a serious one, since the beaches were made almost uninhabitable because of the odor of decaying fishes and the accompanying peculiar gas. This miasma irritated the nose and throat causing troublesome coughing for residents and visitors.

In April, 1947, dead fishes were reported in the outer part of Florida Bay from Cape Florida to Marathon. Studies were carried out and the results of all investigations, together with recommendations to city officials for the purpose of minimizing damage, were published in a bulletin by the Board of Conservation (Ed. Bull. No. 1, original).

During the summer of 1947, Red Tide occurred again, extending northward almost to Tarpon Springs, with greater loss of fishes than during the winter. On this occasion the U. S. Fish & Wildlife Service, the Woods Hole Oceanographic Institution and the Food & Drug Administration also began inquiries. Results of these combined investigations confirmed earlier findings in all respects, but failed to determine the basic causes which brought about the swarming of *G. breve*, and the outbreak dissipated during August, 1947.

Small and sporadic blooms of Red Tide occurred in June-December, 1952, mid-September, 1953, and winter, spring and summer of 1953-54. During this time extensive studies were made by the Florida Board of Conservation and the U. S. Fish & Wildlife Service. Valuable information was obtained on the basic biology of the causative organism, chemistry of the local waters, and general hydrology from Naples to Clearwater.

An outbreak between September 26 and December 10, 1957, resulted in catastrophic mortalities to marine animals along the southwest coast of Florida from Anclote Keys to Cape Sable. Reduced seawater temperatures, turbulence, and high turbidity, brought about by a storm, possibly caused the termination of this outbreak.

On June 4, 1958, a Red Tide was observed in Sarasota Bay with accompanying dead fishes and irritating gases. The following month a report was received that fishes were dying in Upper Tampa Bay, but water samples examined on July 18 showed a large number of *Ceratium* sp., *Gonyaulax* spp., and two species of Ciliophora.

After a period of prolonged and excessive rainfall, the southwest coast of Florida experienced another massive visitation of *G. breve* during the fall and early winter of 1959. Vast numbers of dead fishes were grouped about 16 miles offshore and slightly south of Sanibel Island, extending north to Anclote Keys near Tarpon

Springs. At the height of the outbreak, *G. breve* was extremely abundant in the water samples taken in the area south of the eastern portion of Sanibel Island. The maximum count was in excess of 16,000,000 cells per quart of seawater.

On January 5, 1960, dead fishes and discolored water were observed along the southwest coast near Sanibel Island. Another affected region included the coastal waters from Venice to slightly below Cape Romano. Red Tide conditions in these areas became quiescent by the end of January. On March 25th, a second outbreak developed about 17 miles west of Egmont Key. An aerial observer for the Florida Board of Conservation noted a mass of fish carcasses a few miles west of Chassahowitzka Bay.

A possible Red Tide was experienced from June through September, 1961, when several sightings were reported from Sanibel Island north to Pass-a-Grille.

Scattered blooms occurred from Clearwater south to Lemon Bay near Englewood during the winter of 1962 and early 1963. The presence of *G. breve* in water samples taken in Lemon Bay ranged from 3,000 to 26,000 per quart. Also, other closely related organisms (*Gymnodinium* spp.) bloomed and produced concentrations as high as 1,000,000 per quart.

On April 12, 1963, two Red Tide conditions were recorded off Collier County. One developed about three-fourths of a mile north of the city pier at Naples, and the other slightly north of Clam Pass. Seawater samples taken in the vicinity of the outbreaks showed high concentrations of *G. breve*.

By the middle of April, 1963, another Red Tide took place in Upper and Lower Tampa Bays. Severe fish kills were noted in Lower Tampa Bay near the Sunshine Skyway. Many fishes such as mullet, pinfish, and porcupine fish were identified in the kills. During August and September, 1963, other fish kills were observed north of the Venice Jetties to Anna Maria Island.

In July, 1964, a bloom developed 22-87 miles offshore in Apalachee Bay. Instances of discolored water and dead fishes were seen by commercial fishermen in the northwestern Gulf area near St. George Island late in August of 1964.

On September 3, 1964, an aerial survey was made of the northern portion of the Bay, covering the region from East Pass to the mouth of the Aucilla River. In water ranging in color from dark brown to grayish green, numerous dead fishes were noticed. The following day another aerial survey was made of the area from St. Marks light to the mouth of the Suwannee River. Concentrations of dead fishes were noted from St. Marks light to Piney Point. Another body of discolored water was located about 10 miles off the mouth of the Fenholloway River. Fishermen working near the

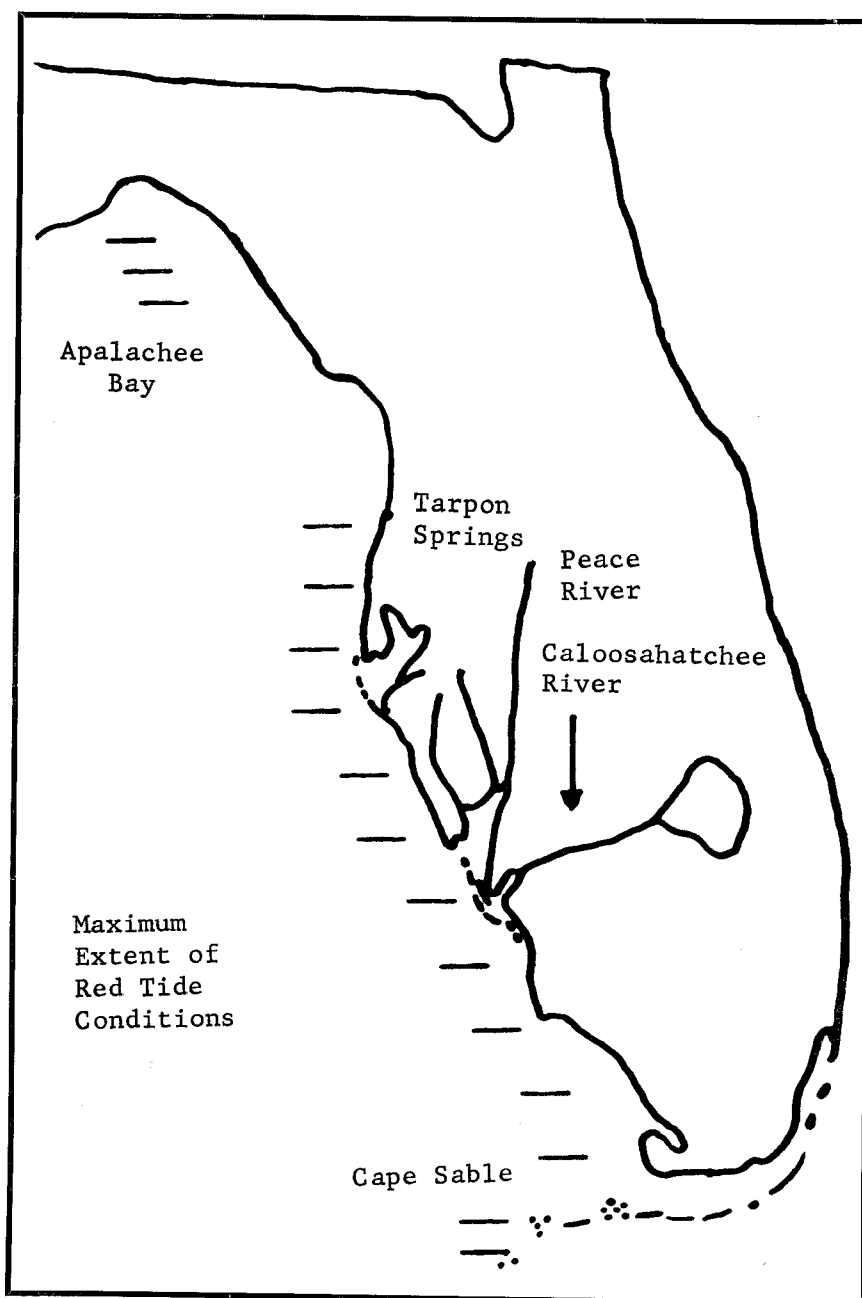


Figure 3. Known areas of Red Tide conditions.

mouth of the river observed a substantial fish kill in the vicinity of Rock Islands during early September, 1964.

5. When and Where Is Red Tide Likely to Return?

Red Tides are neither new nor confined to Florida. These discolorations, which are sometimes accompanied by death of fishes, have been observed in fresh and salt water and were reported by ancient writers as far back as 208 B.C. Several references that probably allude to Red Tide appear in the Bible. In most cases it is probable that the cause was a sudden increase of certain types of microscopic life. According to the kind and concentration of these microscopic organisms, the color of the water might be yellow, green, red, white, blue-green, or blue. Occasionally, discolored water has been seen in the open ocean but most reports are from shallow water in coastal areas and are associated with intense discoloration of seawater without death of fishes. Cases where mortality has probably resulted from Red Tide are recorded from as far back as 1844. Since then the plague has recurred in the years 1854, 1878, 1880, 1882, 1883, 1885, 1908, 1916, 1932, 1946-1947, 1951, 1952, 1953, 1954, 1957, 1958, 1959, 1960, 1961, 1962, 1963, and 1964. Also, recent research has indicated that there were several previously unreported outbreaks.

If it were known what factors are responsible for the increase in amount and concentration of compounds necessary for multiplication of *G. breve* in seawater, it would then be possible to determine the conditions which foster Red Tide. As will be shown later, there appears to be a relatively clear correlation between Red Tide outbreaks and climatological conditions, e.g., periods of high rainfall. Future studies may indicate that conditions such as wind, light-penetration, and temperature are contributing parameters.

6. What Is the Red Tide "Gas"?

An odorless, colorless gas, irritating to eyes, nose and throat, sometimes occurs with outbreaks of Red Tide. The origin of this gas was at one time rumored to be the result of noxious materials such as ammunitions and poisonous gases, dumped into Gulf waters. Via scientific investigations this conjecture has been proven false. The facts listed below are pertinent to the origin of the so-called "gas."

A. Toxic Red Tides are worldwide and not restricted to the dumping grounds of scrap war material.

B. Dr. P. S. Galtsoff (1948) suggested that respiratory symptoms described by Taylor in 1917 were identical with those

experienced during the 1947 outbreak, thereby casting doubt on the gas being caused by noxious war materials.

C. The irritant gas has not been found to exist unless *G. breve* is also present in fairly high concentrations.

D. If samples of Red Tide water are heated, or violently shaken, irritant gas is released. When such water is allowed to remain quiet and cool, no irritation is experienced. Pure seawater, when heated or shaken, does not release irritants.

E. Correlations between onshore winds and the release of irritant gas in Red Tide areas have been made.

F. The particular gas in question is not caused by fish decomposition. While an unpleasant odor stems from dead fishes, there is no similar irritant to that found in Red Tide water.

When subjects breathed seawater spray containing 15 to 56 million Red Tide organisms to the quart, the irritation experienced was the same as that produced by the Red Tide gas. Cotton, about one inch thick, held over the nose and mouth, kept the irritants out (Woodcock, 1948). It should be stressed that the irritating effects to the nose and throat associated with Red Tide gas are temporary. No aftereffects have been reported.

7. Currents and Red Tide

Movements of patches of discolored water and dying fishes which characterize a Red Tide bloom are under study. The counterclockwise current eddy, particularly its eastern portion which flows north off the west coast of Florida, was known prior to the present studies. A careful analysis of the available oceanographic data confirmed the existence of this eddy and in addition, showed several features previously undetected but of immediate importance to Red Tide outbreaks.

First, as water moves offshore toward deeper bottom, it moves as a unit column or "parcel"; this, by necessity, leads to horizontal convergence. As the column becomes longer, and consequently thinner, the edges of the "parcel" approach each other, thus concentrating floating matter to several times its initial volume in a few weeks' time. Factors important to Red Tide may be concentrated by this mechanism offshore. When these are compounded and released as a result of optimal meteorological, biological, and hydrological conditions they may be blown onshore by a westerly wind.

The second undetected feature is that the estuarine waters north of Tampa Bay to Apalachicola participate in the counterclockwise current eddy. These estuarine waters may contain substances important to Red Tide outbreaks.

The third and last feature which will be mentioned is that some

of the water column, following the counterclockwise eddy, will eventually turn toward shoal bottom and shore; in so doing it "flattens" out and deposits whatever Red Tide organisms or debris it may contain, onto shore. Winds affecting surface currents may influence the severity of an outbreak.

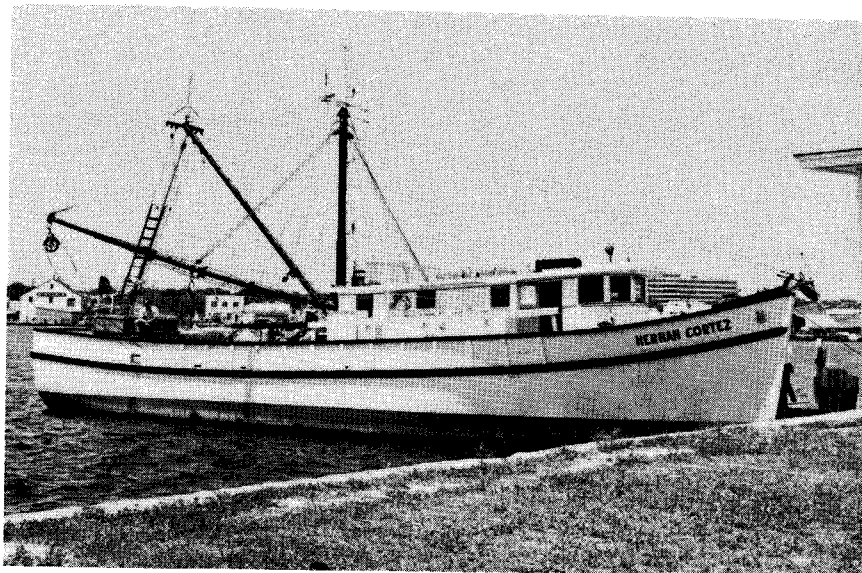


Figure 4. Research vessel *Hernan Cortez* which is being used for biological studies on the Red Tide.

8. What Is Being Done About Red Tide?

Intensified Red Tide research by the Florida Board of Conservation began in December, 1963, and is the most extensive being done in the world at this time. Separate studies of dinoflagellates, diatoms, artificial cultivation of phytoplankton, organic chemistry, inorganic chemistry, vitamin B₁₂, and a bioassay for *G. breve*'s nutritional needs, comprise the program.

Details concerning outbreaks dating back to 1946 are being compiled by a data analyst. The information is being arranged in chronological order and includes aerial surveys, newspaper stories, and individual observations. When this is completed, an ancillary summary of attendant meteorological information will be prepared. In this manner the relationship of various weather characteristics to outbreaks will be evaluated.

The following project summaries are designed to show the current status of Red Tide research.

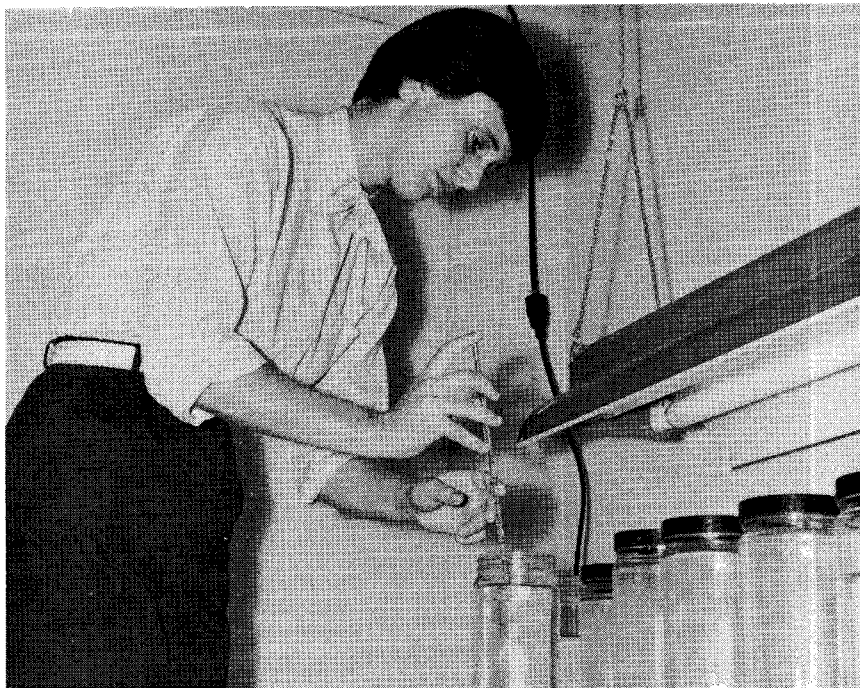


Figure 5. A biologist preparing to examine seawater for *Gymnodinium breve*.

DINOFLAGELLATES:

For years a lack of knowledge has existed concerning the species diversity of dinoflagellates in the Gulf of Mexico. The Florida Board of Conservation Marine Laboratory is preparing a monograph which will describe the dinoflagellate population of the Gulf. Thus far 31 genera and over 100 species and varieties have been identified.

A manuscript has been prepared concerning the unusual outbreak in Apalachee Bay during the summer of 1964. This report establishes a new northern limit for Red Tide in Florida.

DIATOMS:

Biologists seeking information on these lifeforms have two long-range goals: first, to obtain a greater awareness of the range and variety of diatom species in Florida's marine waters; second, to determine if diatoms play a role in the stimulation of Red Tide.

A study of the coastal waters from Tampa Bay to Marco Island has revealed an unanticipated richness of diatoms. The seawater samples taken in the area from November, 1963 to October, 1964, averaged around 1,000,000 organisms per quart.

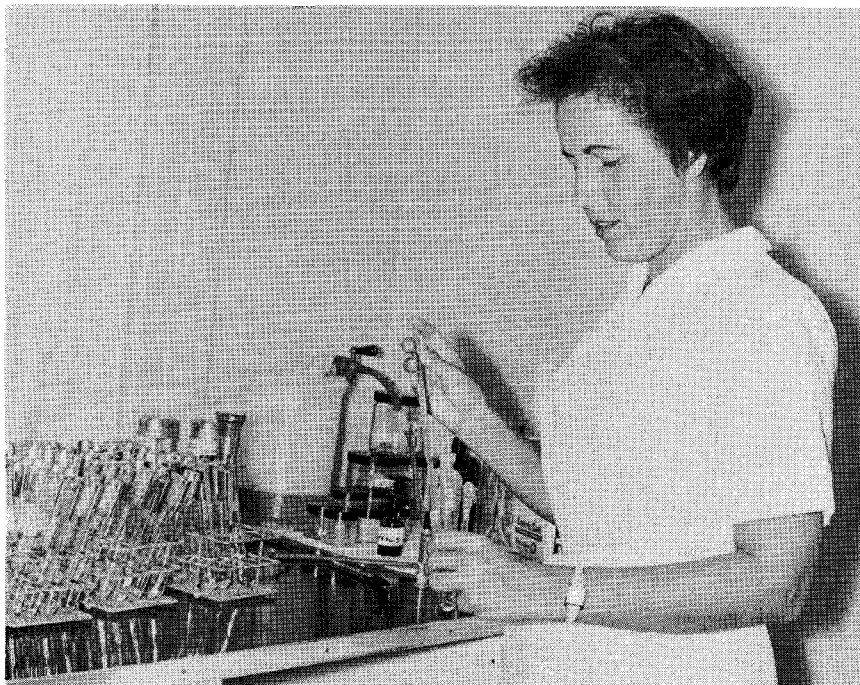


Figure 6. Cultivation in the laboratory of delicate microorganisms is required for a greater understanding of Red Tide.

ARTIFICIAL CULTIVATION OF PHYTOPLANKTON:

Biologists of the artificial culture laboratory isolate and study the physical and nutritional needs of microscopic organisms growing in association with *G. breve*. Organisms were isolated from routine water samples taken from eleven stations and are being grown in both natural and artificial seawater. By adding or subtracting nutritive materials it is possible to define the organism's needs. When we know the nutritional requirements of phytoplankton associated with *G. breve*, we may be able to make useful inferences concerning water quality.

Phytoplankton organisms need a variety of nutritive substances. Among the materials required by different phytoplankters are vitamins, nitrogen, phosphorus, and carbohydrates.

Approximately 40 phytoplankton species have been isolated and grown under laboratory conditions. This culture work has led to five publications, three in print and two in press.

ORGANIC AND INORGANIC CHEMISTRY:

The significance which organic and inorganic substances from land runoff may have as contributory factors to Red Tide is pres-

ently being evaluated. The scientific literature has many references connecting plankton blooms with periods of high rainfall over the adjacent land areas. Furthermore, investigations of Red Tide fish kills along the west coast of Florida have demonstrated their frequent association with water of slightly lower salinity than that found offshore. Statistical evaluation of climatological data by other workers has demonstrated that rainfall could be correlated to Florida's Red Tide. A cycle or series of outbreaks is most likely to occur when annual rainfall is well above the average, as demonstrated in Figure 7. Also, after a period of no Red Tide, the first outbreak most frequently occurs during the fall, especially

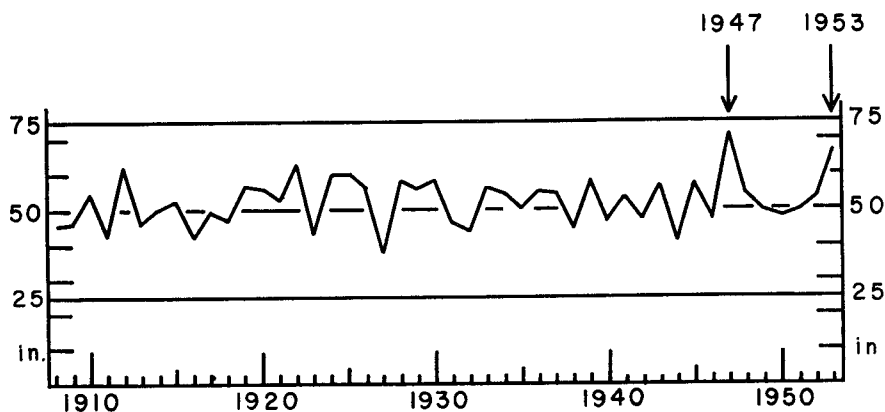


Figure 7. Annual rainfall in Peace River drainage area and the most distinct outbreaks of Red Tide.

in the month of October. Another correlation exists between outbreaks and annual discharge of the Peace River (Figure 8). When the discharge is at a maximum, the probability of Red Tide outbreaks in this area appears higher than normal.

Since the exact way in which rainfall affects Red Tide has not been determined, intensive sampling of the Florida west coast rivers for many inorganic and organic nutrients is being carried out. To date over 500 water samples have been taken from these strategic rivers.

So far, chemical analyses of these water samples have indicated that if rainfall is above normal levels, higher concentrations of tannic acid and iron are present because of the increased land runoff. Iron is a very important nutrient to *G. breve* and the tannic acids help to make it more soluble in seawater. It was also noted that a drop in the phosphorus content of the Peace River occurs during periods of high runoff. Future studies may reveal other relevant correlations.

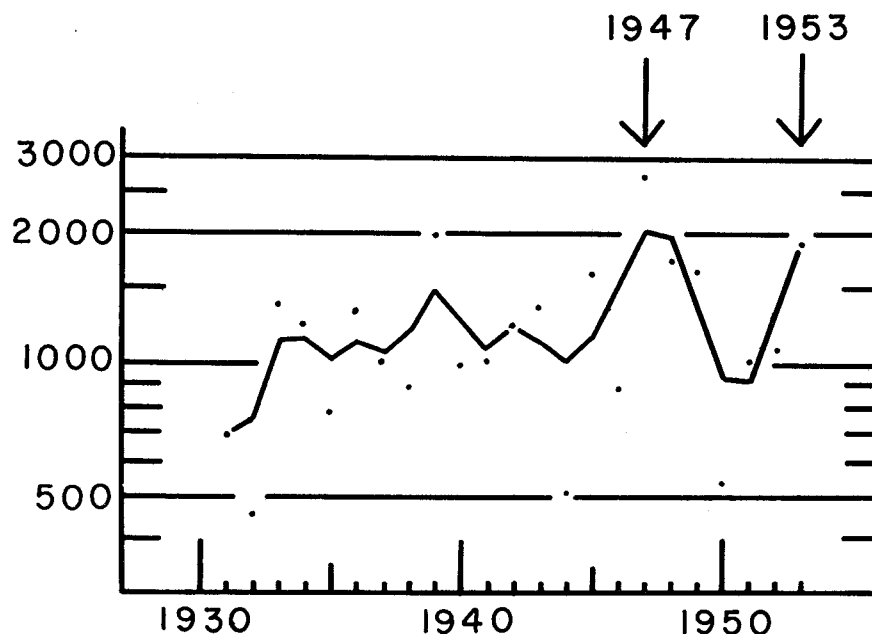


Figure 8. Correlation of annual discharge of Peace River in cubic feet per second to two major Red Tide outbreaks.

VITAMIN B₁₂:

The primary concern is to determine vitamin concentrations in seawater that affect the growth and reproduction of *G. breve* and associated organisms.

A study of the family of compounds usually grouped as vitamin B₁₂ indicates that their presence in seawater may enhance the Red Tide organism's growth. It has been established that high concentrations of B₁₂ are typically found close to shore and that low amounts are a feature of deeper, offshore areas. Two possible sources of B₁₂ have been considered by scientists. One is land drainage which may contain organic substances; the other involves by-products of bacterial action in bays, marshes, and sequestered waters. Both theories are being investigated and no conclusions have been reached.

BIOASSAY FOR NUTRITIONAL REQUIREMENTS OF *G. BREVE*:

Studies using bioassay methodology can demonstrate the nutritional needs of *G. breve*. From these results it can be ascertained which supplements added to seawater samples stimulate growth and reproduction of this organism.

Data at this time indicate that addition of EDTA (eth-



Figure 9. Biologists preparing to take a photomicrograph of *Gymnodinium breve*.

ylenediamine tetra-acetic acid) and/or FeEDTA enhances more samples than any other supplement. Both of these substances act as chelators which possess the chemical ability to make trace elements more available to the microorganisms. It is specifically believed that these chelators render iron more suitable for use than that which normally exists in seawater. Also, from these data there is an indication that Na_2S , while not of direct nutritional value, favorably influences the seawater, thereby stimulating growth of *G. breve*.

9. Can Red Tide Be Controlled?

Our present theories indicate that control is not only possible but practical. Much evidence has been developed to show that heavy land runoff and associated nutrients are essential to the development of massive Red Tides. The most practical control measure, then, becomes the creation of dams across major streams. These will prevent large, rapid deliveries of fresh water into coastal areas. Flood waters will be retarded, to be discharged slowly over a period of several months.

In order to retain estuaries in their natural state, and to insure their productivity, dams should be placed upstream or at the mouth of the river. Dams should not be located across inlets, bay mouths or any other place where large areas of normally brackish shallow water nursery and sanctuary habitats would be destroyed by accumulated fresh water.

10. Florida Board of Conservation Publications Emanating from Red Tide Studies

Donnelly, P., *et al.*

A study of contributory chemical parameters to Red Tide in Apalachee Bay.

Donnelly, P. and M. A. Burklew

Amino acids in Florida Gulf Coast waters and in artificial cultures of marine algae.

Donnelly, P., R. Overstreet, J. Vuille, and M. A. Burklew

Chemical content of river waters in southwest Florida.

Donnelly, P., M. Jayaswal and J. Vuille

Iron determinations of the coastal waters from southwest Florida.

Saunders, R. and C. Wahlquist

Diatoms and their relationship to *G. breve* Davis.

Saunders, R., J. Williams, B. Birnhak, J. Davis and C. Wahlquist

Seasonal distribution of diatoms in Florida water from Tampa Bay to Marco Island, Florida, during 1964.

- Steidinger, K. and J. Davis
Observations on *G. breve* Davis and other dinoflagellates.
- Steidinger, K., J. Davis and J. Williams
Dinoflagellate studies on the inshore waters of the west coast of Florida.
- Stewart, V., H. Wahlquist and R. Burket
Distribution of vitamin B₁₂.
- Stewart, V., H. Wahlquist and R. Burket
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