STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES

Randolph Hodges, *Executive Director*

EDUCATIONAL SERIES
NO. 17

FLORIDA RED TIDES

Karen A. Steidinger and Edwin A. Joyce, Jr.

April 1973

Marine Research Laboratory
Florida Department of Natural Resources
St. Petersburg, Florida

This public document was promulgated at an annual cost of $ 1,274 or $ .25 per copy to make research results and marine resources information available to scientists and the public.

Contents

Abstract 1
Historical Resumé 2
Causative Organism 6
Toxicity 10
Public Health Problems 12
Economic Effects 12
Conditions Favoring Red Tides 13
Prediction and Early Detection 15
Control 16
Present Research 18
Acknowledgments 19
Pertinent References 20
Appendix 26

FLORIDA RED TIDES

Karen A. Steidinger and Edwin A. Joyce, Jr.

ABSTRACT

The first documented fish kill associated with discolored seawater in Florida occurred in 1844, but the causative organism, *Gymnodinium breve*, was not identified until 1948. Red tides and research results over the last 20 years are discussed and summarized. Red tide is a natural occurrence. Control is not presently feasible and may not be ecologically advisable even if available. Present research is directed toward a better understanding of red tides and their effects.

INTRODUCTION

Red tides are natural phenomena along the Florida Gulf coast, but major incidents are sporadic. In this paper "red tide" implies blooms of a toxic organism discoloring seawater and causing death of fishes, invertebrates or sea birds. The discoloration in Florida coastal waters is caused by high concentrations of a poisonous microscopic dinoflagellate, *Gymnodinium breve*. It is the poison or neuromotor toxin produced by hundreds of thousands of these cells that kills animals, mostly fishes.

Other types of fish kills also occur in inshore and bay waters, particularly during summer months. However, most are caused by nontoxic microorganisms that remove oxygen from the water. These plant-like organisms photosynthesize and respire during the day, adding oxygen to seawater, but at night photosynthesis ceases and respiration consumes oxygen. During "blooms" (increased concentrations of microorganisms sometimes reaching millions of cells per liter), this process plus bacterial respiration deplete oxygen, and

---

Contribution No. 220, Florida Department of Natural Resources Marine Research Laboratory

marine animals essentially suffocate, particularly in early morning hours. Short-term summer oxygen-depletion kills usually occur in shallow waters and affect most animals.

Red tides are fairly common throughout the world in areas of seawater upwelling or river discharge. They have been observed for many years in South Africa, India, Australia, Japan, Peru, Scandinavia, Great Britain, Canada, and Mexico. Within the United States they have been recorded in Washington, California, Texas, Florida, and New England. Most red tides are caused by species of the dinoflagellate genus *Gonyaulax*.

HISTORICAL RESUMÉ

The first documented Florida fish kill suspected to have been caused by a red tide occurred in 1844. Similar incidents of fish kills and water discoloration were reported in 1854, 1856, 1865, 1878, 1879, 1880, 1882, 1883, 1884, 1885, 1908, 1916, and 1935 (Rounsefell and Nelson, 1966). However, it was not until the 1946-1947 fish kill that the causative organism was isolated and identified as a dinoflagellate new to science. Dr. C. C. Davis named this toxic microorganism *Gymnodinium brevis*, later corrected to the now familiar *Gymnodinium breve*.

This first scientifically studied *G. breve* red tide appeared in November 1946, along the southwest coast of Florida near Naples (Figure 1). Fishermen reported large numbers of dead and dying fish from about 16 to 24 kilometers (10 to 15 miles) offshore. Subsequently, marine mortalities increased and the red tide was also reported further north. By the end of January 1947, bays and beaches at Ft. Myers, Sanibel Island, and neighboring areas as far north as Englewood were littered with millions of dead fish. Disposal of dead fish became a serious problem, as did odors of decay and a peculiar "gas" which caused temporary eye, nose, and throat irritations.

In April 1947, dead fish were reported in the outer part of Florida Bay from Cape Sable to Marathon. During summer of 1947, red tide occurred again, extending northward almost to Tarpon Springs, with greater losses than during the previous winter. At this time, the U.S. Fish & Wildlife Service, the Woods Hole Oceanographic Institution, and the Food and Drug Administration began investigations which confirmed earlier findings but failed to determine basic causes of *G. breve* proliferation. The bloom dissipated

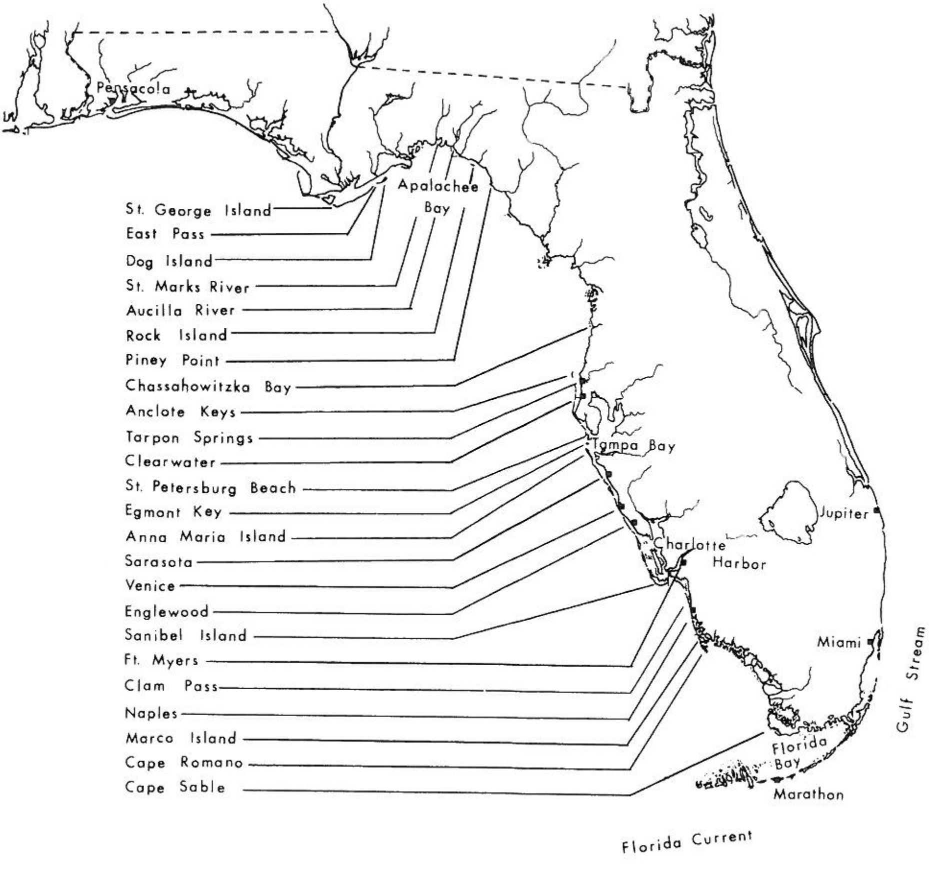

Figure 1. Florida and adjacent coastal waters.

during August. The 1946-1947 outbreak, because of its extent and duration, is the most severe Florida red tide on record.

Small, sporadic *G. breve* blooms occurred in June to December 1952, mid-September 1953, and winter, spring, and summer 1953-1954. During this time extensive studies were made by the Florida Department of Natural Resources (then the Florida Board of Conservation) and the U.S. Fish and Wildlife Service. Valuable information was obtained on basic biology of the causative organism, chemistry of local waters, and general hydrology from Naples to Clearwater.

An outbreak between 26 September and 10 December 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 storm-induced turbidity probably caused termination of this bloom.

On 4 June 1958, red tide with associated dead fish and irritating "gases" was observed in Sarasota Bay. The following month a report was received that fish were dying in upper Tampa Bay, but water samples examined on 18 July showed no *G. breve*. This kill was probably caused by oxygen depleted waters.

After a period of prolonged and excessive rainfall, the southwest coast of Florida experienced another *G. breve* red tide during fall and early winter of 1959. Vast numbers of dead fish were grouped from about 26 kilometers (16 miles) offshore and slightly south of Sanibel Island north to Anclote Keys. At the peak of the outbreak, *G. breve* was extremely abundant (greater than 16 million cells per liter) off Sanibel Island.

In early January 1960, dead fish and discoloration were observed in coastal waters from Venice to slightly below Cape Romano. Red tide conditions in these areas dissipated by the end of January. On 25 March, a second outbreak was reported about 27 kilometers (17 miles) west of Egmont Key. Aerial observations also revealed dead fish a few miles west of Chassahowitzka Bay. Another incident suspiciously like red tide (reddish seawater and dead fish) was reported to be 48 to 64 kilometers (30 to 40 miles) off Pensacola in early July, but no water samples could be obtained (for an account, see Ingle and Williams, 1966).

A possible outbreak was experienced from June through September 1961, when several sightings of discolored water were reported from Sanibel Island north to Tampa Bay. However, the discoloration could have been the blue-green alga, *Oscillatoria erythraea*, which commonly occurs during spring through fall along the west coast of

Florida.

Scattered *G. breve* blooms occurred from Clearwater south to Lemon Bay near Englewood during winter 1962-1963. Counts in Lemon Bay samples ranged from 3,000 to 26,000 cells per liter. In addition, other *Gymnodinium* species bloomed and produced concentrations as high as 1 million cells per liter.

On 12 April 1963, two red tide areas were recorded off Collier County. One developed about one kilometer (3/4 mile) north of the city pier at Naples, the other slightly north of Clam Pass; samples showed high concentrations of *G. breve.* In mid-April, another red tide occurred in upper and lower Tampa Bay. Severe fish kills were noted in lower Tampa Bay near the Sunshine Skyway bridge. Many fishes, such as mullet, pinfish, and porcupine fish were identified in the kills (for an account, see Florida Board of Conservation, 1964). During August and September, other fish kills were observed from north of the Venice jetties to Anna Maria Island.

In July 1964, a *G. breve* bloom developed 35 to 140 kilometers (22 to 87 miles) offshore in Apalachee Bay. Discolored water and dead fish were observed by commercial fishermen in the northeastern Gulf near St. George Island in late August. On 3 September an aerial survey was made of northern Apalachee Bay, covering the region from East Pass to the mouth of the Aucilla River. Numerous dead fish were noted in water ranging from dark brown to grayish green. The following day another aerial survey detected dead fish from St. Marks lighthouse to Piney Point. In addition, fishermen working the Fenholloway River mouth observed a substantial fish kill near Rock Island during early September. The area affected during this entire outbreak was estimated to be about 36,257 square kilometers (14,000 square miles). This red tide constituted the first documented *G. breve* bloom in Florida waters north of Tarpon Springs (for an account, see Florida Board of Conservation, 1966).

A minor red tide occurred in October 1966, off Tampa Bay. This outbreak immediately followed an unusual *Gonyaulax monilata* (another toxic dinoflagellate) bloom in August and September that produced fish kills in coastal waters from Anna Maria Island to Cape Romano (for an account, see Williams and Ingle, 1972).

On 27 August 1967, a fish kill was reported 16 kilometers (10 miles) west of St. Petersburg Beach. The outbreak developed into major proportions and lasted until November. Fish kills off the Ft. Myers-Marco area were reported on 29 December. This bloom was of short duration, terminating in late January 1968, but counts as high as 10 million *G. breve* per liter were recorded (for an account, see Morton and Burklew, 1969).

A minor red tide developed in the northeastern Gulf during October 1970. At almost the same time (late August and September) another *G. breve* outbreak occurred, producing fish kills and mild respiratory irritations along the coast of the Bay of Campeche, Mexico (Smithsonian Institution Center for Short-lived Phenomena, 1971).

In summer 1971, a red tide that originated offshore moved into Tampa Bay. Prior to the Tampa Bay incident, an April fish kill in Sarasota Bay was the first sign of this organism in bloom proportions since the previous fall. On 28 May, dead fish were reported along the Ft. Myers-Englewood coastal areas. By June, beached fish were common as far north as Tampa Bay (Figure 2). Red tide conditions in the bay and adjacent nearshore waters lasted until September. Another *G. breve* bloom occurred 5 to 13 kilometers (3 to 8 miles) off Dog Island in the northeastern Gulf in late September. The Tampa Bay outbreak was publicized as one of the worst on record; actually it was only a moderate red tide (3 1/2 months and locally limited fish kills) and certainly did not compare to the 1946-1947, 1953-1954, or 1957 red tides (for an account, see Steidinger and Ingle, 1972).

In late September 1972, a minor red tide developed offshore from the Sanibel Island area. In November, reports of scattered dead fish and eye and upper respiratory irritations were received from Jupiter to Miami on the Florida east coast. Biologists investigating the incident confirmed a *G. breve* outbreak, the first documented in east coast waters. Water samples collected from the southern Gulf of Mexico, Florida Current, and Gulf Stream contained low to moderate concentrations of *G. breve*, suggesting that water currents were transporting Gulf *G. breve* populations around the tip of Florida and up the east coast. Gulf Stream offshoots, or eddies, then evidently forced *G. breve* into inshore waters where they encountered good nutrient and weather conditions. By December, *G. breve* had diminished along both coasts.

CAUSATIVE ORGANISM, *Gymnodinium breve*

Gymnodinium breve Davis is a marine dinoflagellate (Pyrrhophyta: Dinophyceae) usually restricted to Gulf of Mexico and Caribbean waters. A typical *G. breve* cell is small, 20 to 40 μ wide

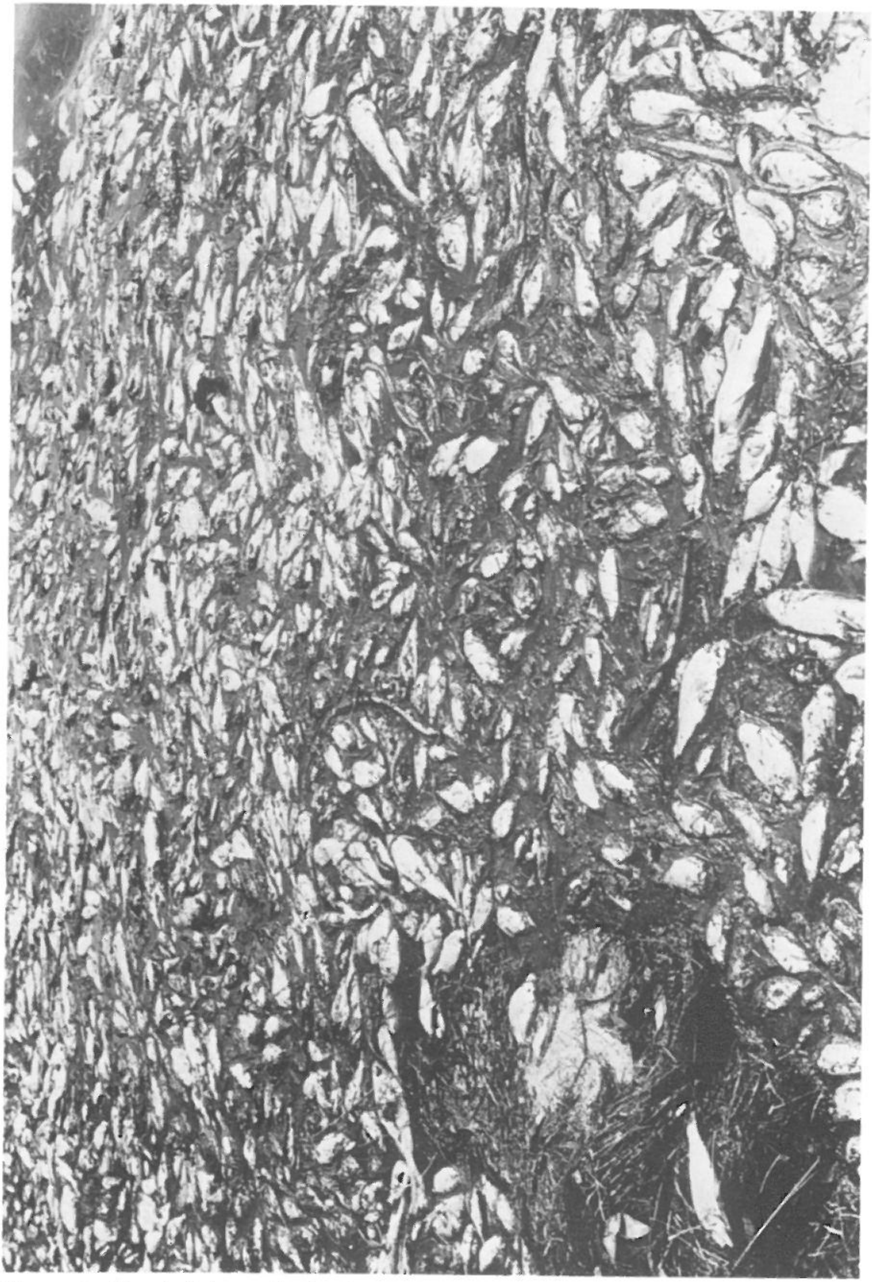

Figure 2. Dead fish washed ashore during the 1971 red tide in Tampa Bay, Florida.

(about 1/1000 inch), slightly broader than long, ventrally concave, and dorsally convex (Figure 3). It is unarmored (without external plates arranged in series). The furrow (cingulum) encircling the cell is typically displaced (one end below the other) about 1 to 2 cingular widths. Proximal and distal ends do not overlap. The cingulum houses a transverse flagellum that aids the cell in propulsion. A longitudinal furrow, located ventrally, is called the sulcus. The posterior half of this furrow houses another flagellum that aids in directional movement; the anterior half is directed to the left (organism's left side). The anterior half of the cell, above the cingulum, is called the epicone and is occasionally longer than the hypocone (posterior half). The epicone typically has a distinctive dome-like hump (overhanging apical process) at the apex. This process, best seen in lateral view, is bordered by the sulcus on the lower left and by an apical indentation on the right. The hypocone appears slightly bilobed.

Internally, *G. breve* has a typical dinophycean nucleus (resembling a fingerprint) located in the posterior left side. The cell also contains about 10 to 20 irregularly shaped yellowish-green, yellowish-brown, or bright yellow chloroplasts, usually near the cell periphery. Depending on the physiological state of the organism, it can have numerous small globular vesicles; however, at least two larger refractive bodies are usually distinct in the hypocone.

The motile stage of *G. breve* resembles a falling leaf as it swims slowly, turning over and over through the water. It has been estimated that dinoflagellates move at a rate of about one meter per hour. *Gymnodinium breve* is positively phototactic (is attracted to light) at moderate light intensities; consequently, during daylight hours it is more concentrated in surface waters.

Under adverse conditions, *G. breve* encysts (forms resting-type spores), going through the following stages: 1) cell loses flagella or reabsorbs them, 2) cell rounds out losing convexity-concavity, and 3) cell shrinks. There is no known way for an inexperienced observer to identify the organism in Stages 2 and 3 because it has lost specific characters such as apical hump, sulcus, and cingulum. However, if the cell can be made to excyst it will eventually reassume its characteristic form.

Davis (1948) originally described *G. breve* as having a circular cingulum (not displaced) and a centrally located nucleus; he did not mention any convexity-concavity. *Gymnodinium breve*, like many unarmored dinoflagellates, assumes a variety of different morpho-

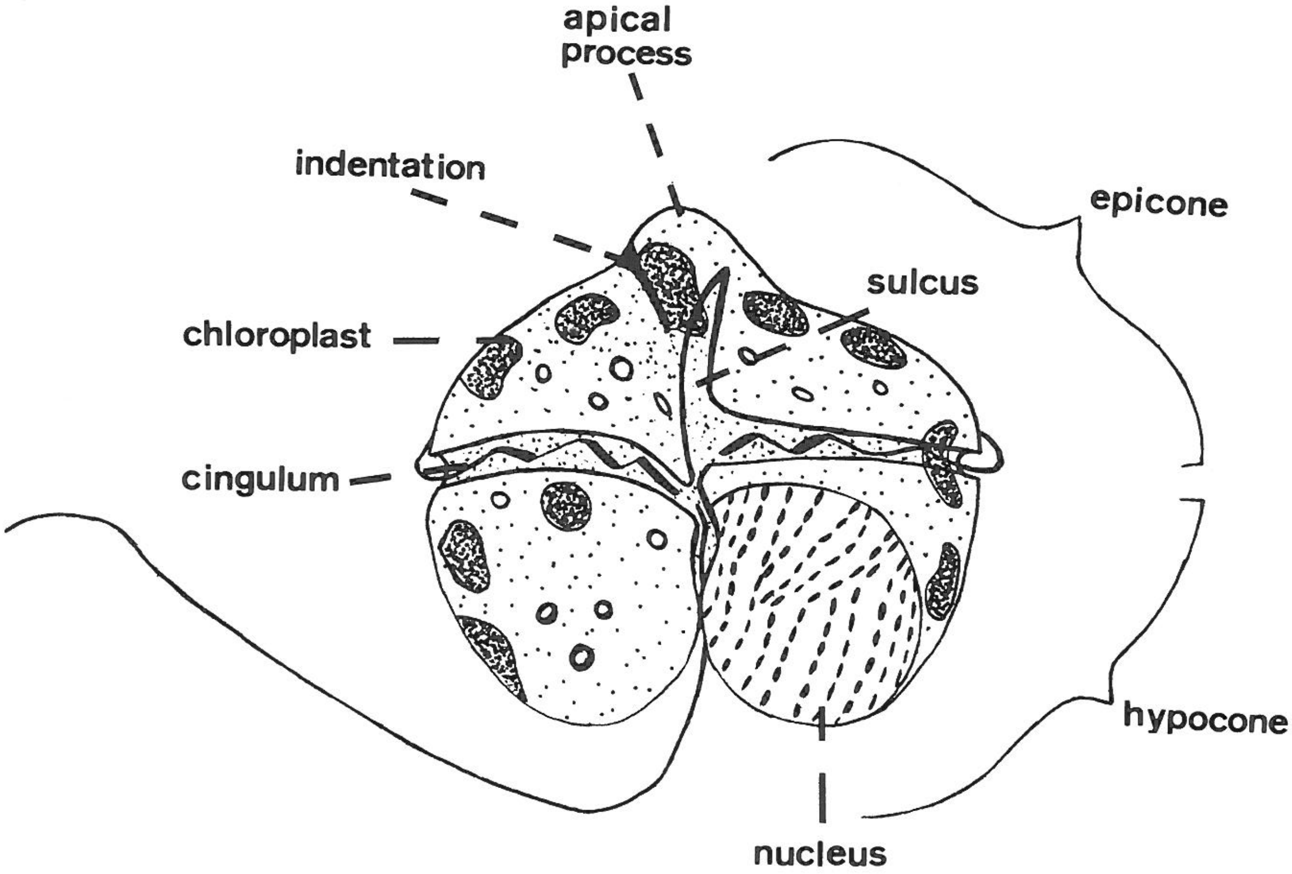

Figure 3. *Gymnodinium breve.* Ventral view.

logical forms either in culture or nature (Steidinger, Davis and Williams, 1966; Dragovich, 1967; Wilson, 1967). However, even if cingular displacement and cellular concavity are ignored, *G. breve* can still be identified by the apical dome-like hump, extent and direction of sulcal intrusion of the epicone, and apical indentation. The *G. breve* form described herein is the one most commonly encountered since 1964 and probably existed prior to that time.

Chemical compositions of two different media used to grow and maintain *G. breve* are presented in an appendix following the text. One, B-5, is an enriched natural seawater medium; the other, NH-15, is an artificial medium not requiring accessibility to "offshore" seawater. References useful for media preparation techniques and necessary equipment are: Wilson, 1966; Collier et al., 1969; Cummins and Stevens, 1970; Brydon et al., 1972. Most cultured *G. breve* are very fragile; consequently, heat, desiccation, surface tension, osmotic stress, and other adverse conditions cause it to rupture within a short period of time. However, field specimens appear more resistant to stress and are more readily examined microscopically.

Gymnodinium breve is photosynthetic, transforming light energy, carbon dioxide, and water into chemical energy and producing its own organic food. More specifically, it is auxotrophic, requiring additional nutrients and other growth factors (e.g., vitamins) to survive. Most dinoflagellates and other phytoplankters are auxotrophs. Phytoplankters comprise the "grass of the sea" and are primary producers at the base of the food chain. These microscopic plant-like protists contribute to the survival of animals via the food chain and are credited with the original production of much of the earth's atmospheric oxygen.

TOXICITY

Most marine microorganisms causing fish kills and bivalve toxicity are dinoflagellates belonging to the genera *Gymnodinium*, *Gonyaulax*, *Amphidinium*, and *Cochlodinium*, but only about 20 of 1,000 or more dinoflagellate species produce toxins and these vary in potency. For example, *Gonyaulax catenella*, a species from the northeast Pacific coast, produces a toxin 100,000 times as potent as cocaine. Filter-feeding bivalves (e.g., mussels, clams, and oysters) exposed to this organism accumulate and store the toxin causing illness and sometimes death when consumed. In contrast, *Gymnodinium breve* toxin is milder; no human fatalities from eating bivalves exposed to *G. breve* or its toxin have been reported, although there are a few records of human illness and distress.

Public health officials periodically monitor shellfish beds to determine presence of toxic live oysters and clams. When a red tide is verified by examination of water samples, officials increase sampling efforts to establish when areas should be closed to harvesting. Shellfish toxicity is determined using the mouse bioassay method whereby laboratory mice are injected with extracted toxin and observed for characteristic signs of distress. Recently Martin, Martin, and Padilla (1972) suggested that toxicity levels can be assessed by hemolytic activity (destruction of red blood cells) of the toxin. This method is faster, more convenient, and certainly deserves evaluation.

Two separable neurotoxic fractions have been recognized. Steidinger, Burklew, and Ingle (1973) reviewed the physiological, toxicological, pharmacological, and chemical aspects of *G. breve* toxin(s). Briefly, *G. breve* produces a neuromotor toxin that appears to depolarize excitable membranes and block nerve impulses. Spikes (1971) summarized the effects on mice, rats, and frogs as: evocation of action potentials, followed by inhibition of these potentials (by depolarization), then contraction of skeletal muscles, and finally, death from respiratory failure. In humans, ingestion of toxic shellfish produces the following sequence of symptoms: tingling sensations in mouth and extremities, motor incoordination, hot-cold flashes, slowed pulse, pupil dilation, mild diarrhea, followed by recovery in a few days (McFarren et al., 1965).

Certain fishes are more susceptible to *G. breve* toxin than others. For example, catfish, eels, and other bottom- dwelling species appear more susceptible than species living higher in the water column. Larger fishes, because of their size or physiological resistance, are less affected unless physically confined or ethologically restricted (e.g., territorial reef fishes). In addition, most invertebrates are rarely killed during red tides with the notable exception of the horseshoe crab (*Limulus polyphemus*) and several gastropods. *Gymnodinium breve* toxin appears to affect primarily those animals with a specialized central nervous system. However, symptoms indicate that the peripheral nervous system is affected more than is the central nervous system in these animals.

Normally, *G. breve* occurs in seawater off the west coast of Florida in quantities less than 1,000 cells per liter and is harmless in such concentrations. Toxin sufficient to cause fish kills is present only when *G. breve* reaches hundreds of thousands of cells per liter.

PUBLIC HEALTH PROBLEMS

The most noticeable effects of red tides are dead fish accompanied by unpleasant odors, flies, and high bacterial counts. Clean-up crews usually remove or bury dead fish within hours after they are beached.

Occasionally, people swimming in red tide waters experience skin irritations but others swimming in the same area may not be affected. Such irritation may result from high concentrations of bacteria or from allergic reactions.

Irritation from what has previously been called red tide "gas" is actually caused by sea spray containing *G. breve* fragments. Wave action and winds destroy *G. breve* cells, producing air-borne toxic particles that cause temporary respiratory distress. Woodcock (1948) noted that a cotton pad, about one-inch thick, held over the nose and mouth prevented irritation.

An additional public health problem arises when people disregard posted signs or warnings and collect shellfish from "closed" areas. Prakash et al. (1971) summed up this problem as it relates to paralytic shellfish poisoning (PSP) in eastern Canada: "Essentially, today's PSP control problem is not technological although it has technological aspects. It is mainly a public education problem and requires new approaches." The same is true regarding Florida's shellfish beds during red tide outbreaks.

ECONOMIC EFFECTS

Lackey and Hynes (1955) stated that sports fishing was "generally good" off the Sarasota area following the 1953-1954 red tide. Springer and Woodburn (1960) summarized several reports to this effect following the 1957 outbreak off Tampa Bay but noted a possible decline in sea bass. During the 1971 outbreak along the lower west coast, inshore reefs were definitely affected but appeared to recover quickly (Steidinger and Ingle, 1972). Moe (1963), based on reports from fishermen, suggested that red tides may have a serious, relatively long-term effect on offshore reef fishing. Recent data indicate that offshore reefs were severely affected during the 1971 red tide (Gregory Smith, University of South Florida Biology Department and Florida Department of Natural Resources Marine Research Laboratory, personal communication). Following the 1972 east coast outbreak, sport fishing success has been some of the best on record (John Jolley, Florida Department of Natural Resources Field Laboratory, West Palm Beach, Florida, personal communication), indicating that effects are temporary, at least for pelagic fishes (e.g., mackerel, kingfish, sailfish, cobia).

Commercial fishing statistics, although imprecise, do not indicate catch declines following severe red tides (Springer and Woodburn, 1960). Gunter et al. (1948) estimated 500 million fish killed by the 1946-1947 red tide. By considering these at ten to the pound, Rounsefell and Nelson (1966) concluded that the total red tide kill was about 25,000 tons, equivalent to only 10% of the annual menhaden catch. This should be considered a minimum, since these and most other estimates are based only on dead fish cast up on beaches and do not consider fishes which never float or those which sink prior to reaching beaches. Most fishes killed, however, are generally not considered of immediate economic (commercial or sports) importance; this may be a factor in the observed lack of declines in fish landings following red tides.

Economic impact in areas affected by red tide is felt more severely in the tourist industry. Sensationalized reports concerning red tides and their damages result in the potential Florida visitor remaining at home or going elsewhere to spend his vacation. Dead fish are usually removed from beaches as soon as possible, but even their temporary presence is unpleasant to many tourists. It is difficult to place a monetary value on red tide damage. La Crossitt (1954) estimated a 3.8 million dollar loss to Clearwater, Florida, during the 1953-1954 red tide. He reported that Ft. Myers, a city outside the affected area, also lost about 0.5 million dollars. In the recent 1971 red tide, St. Petersburg city officials estimated that it cost $155,763 merely to remove dead fish over a three-month period.

CONDITIONS FAVORING RED TIDES

Salinity and temperature are obvious factors regulating occurrence and distribution of marine organisms. *Gymnodinium breve* is a coastal species rarely found in estuaries. However, on occasion *G. breve* survives and prospers in bays when recruitment from coastal waters coincides with higher than normal estuarine salinities and favorable nutrient conditions (Steidinger and Ingle, 1972). The low salinity barrier of embayments usually protects upper bay shellfish beds from exposure to *G. breve.* Laboratory studies indicate an optimal salinity range of 27 to 37 o/oo (parts per thousand) for *G. breve* (Rounsefell and Nelson, 1966); salinities below 24 o/oo are thought to be inhibitory.

Gunter (1957) and others consider temperature the major factor in limiting species distributions. Temperature is a regulating factor in the distribution and occurrence of *G. breve*; blooms have been observed in waters ranging from 15 to 33°C (Rounsefell and Nelson, 1966; Steidinger and Ingle, 1972), but prolonged water temperatures at the range extremes appear to be deleterious, as do sudden cold spells.

Gymnodinium breve requires nutrients such as inorganic nitrogen and phosphorus, sulfides, and various salts common to phytoplankton growth. Factors such as chelators, vitamins, and possibly external metabolites also play valuable roles. Early research concentrated on whether or not basic nutrients and growth promoters were initiating red tides. Results indicated that phosphates and vitamin B_{12} are continually available in optimal amounts in seawater and therefore are not limiting.

Correlation of heavy rainfall with initiation of red tides (Figure 4) was noted early in the history of red tide research (Slobodkin, 1953; University of Miami Marine Laboratory, 1954), but a possible explanation was not offered until the mid-1960's. Laboratory studies by Wilson (1966) showed that chelated iron (EDTA•Fe) enhanced *G. breve* growth. Researchers subsequently speculated that trace elements bound by naturally occurring chelators (e.g., humic substances) in land runoff contribute to the initiation of red tides. Later, Ingle and Martin (1971) developed a prediction index based on iron discharge by major tributaries (see *Prediction and Early Detection*).

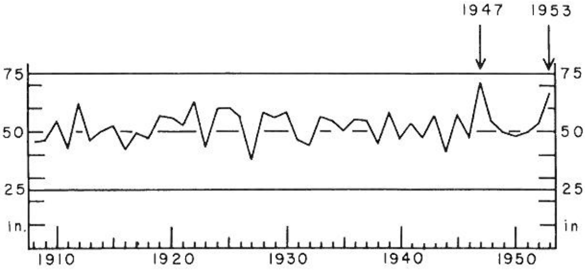

Figure 4. Annual rainfall in Peace River drainage area and the most distinct outbreaks of red tide.

Ironically, dinoflagellates are known for their facility to thrive in nutrient-poor water; dinoflagellate blooms often follow diatom blooms when inorganic macronutrients are less readily available (Ryther, 1955). Nevertheless many dinoflagellate blooms (toxic or nontoxic) that cause fish kills occur in nutrient-rich waters such as estuaries or coastal upwellings.

Light is another important factor in initiation of phytoplankton blooms, particularly in temperate regions. However, relatively little is known about effects of differing light wavelengths and periodicities on *G. breve* blooms in subtropical-tropical waters. Aldrich (1960) found that *G. breve* was destroyed by ultraviolet and that it "preferred" blue, green, or polarized light, but effects of other wavelengths have not been investigated. Light intensities below 200 foot-candles are thought to be limiting (see Rounsefell and Nelson, 1966).

Perhaps some of the most influential and critical physical forces contributing to formation of red tides are winds, tides, currents, and density gradients. Even if all other factors are optimal, these physical forces can disperse or concentrate *G. breve* populations. For example, like most dinoflagellates, *G. breve* probably divides no more than once per day, yet cell count increases far in excess of these division rates are sometimes observed, suggesting that other processes are contributing to higher cell counts (Steidinger and Ingle, 1972). Plankton blooms usually occur during periods of calm weather or gentle onshore winds (less than 13 knots) but continued wind velocities greater than 16 knots could dissipate *G. breve* (Rounsefell and Nelson, 1966). Pomeroy et al. (1956) observed that wind velocities of 7 to 10 knots terminated a mixed bloom of *Gymnodinium splendens* and *Amphidinium fusiforme* in Delaware Bay, but 4 to 6 knots winds favored the bloom.

In summary, salinity, temperature, light, nutrients, vitamins, chelators, winds and currents all play a part in the success of red tide. Any suboptimal factor may terminate a bloom or prevent a potential bloom from reaching major proportions.

PREDICTION AND EARLY DETECTION

It has recently been suggested (Ingle and Martin, 1971; Steidinger and Ingle, 1972) that *G. breve* blooms occur every year in coastal areas of the Gulf of Mexico, such as Apalachee Bay, the Campeche coast, or the Tampa Bay-Charlotte Harbor area. If conditions at the time of initial development are optimal (calm seas, gentle onshore winds, suitable salinity and temperature), then the bloom will progress from a minor to major outbreak.

Ingle and Martin (1971) were the first to propose a method of predicting major Florida red tides. They stated that if and when the iron content of the Peace River discharge (monitored at Arcadia, Florida) reached 235,000 pounds over a three-month period, a red tide could be forecast off the Charlotte Harbor area. Their conclusions were based on statistical analyses of data collected over 25 years. They did not imply that the trace metal iron was the "triggering" factor, but only suggested it as an index. Trace metals in seawater are made more available (soluble) to phytoplankton by being complexed or chelated. Coincidental with the large iron discharge is a correspondingly large humic fraction (plant decomposition products that turn river water coffee-colored) which acts as a natural chelator in the coastal marine environment.

Another possible method of prediction is by monitoring *G. breve* cell counts in coastal waters. Motile *G. breve* usually occur in inshore Gulf waters in low concentrations. If counts increase to 5,000 cells per liter, it can be stated that a red tide is developing and, if other conditions are favorable, a major red tide could occur. Biweekly sampling at selected coastal sites where *G. breve* blooms have previously occurred could be a regular County or State program. The advantage of early red tide prediction lies in forewarning local officials so that proper equipment and manpower can be on emergency call. However, both prediction methods need to be tested for usefulness and effectiveness.

CONTROL

The advisability of controlling red tides (even if a method were available) has become a controversial subject. However, when the St. Petersburg Times (17 July 1971) polled various red tide specialists (Dr. Sammy M. Ray, Texas A & M University; Dr. Dean F. Martin, University of South Florida; Dr. John J. Sasner, University of New Hampshire; Dr. Z. Paster, University of California; Mr. Robert M. Ingle, then of the Florida Department of Natural Resources; and one of the authors) the consensus was that controlling Florida red tides, after they start, is not presently feasible. Reasoning behind this statement involves problems of both area and volume. Red tides can occur from shore to 64 kilometers (40 miles) or so offshore along the entire west and much of the northwest coast of Florida, sometimes encompassing areas as great as 36,257 square kilometers (14,000 square miles). The organism can be distributed throughout the water column to depths as great as 38 meters (123 feet).

Chemical control was previously considered a plausible means of destroying *G. breve* blooms. The U.S. Department of Interior sponsored research to find an inexpensive, readily available, and partially selective chemical that would kill (100% mortality) cultured *G. breve* in 24 hours at 0.01 parts per million. Over 4,500 chemicals (primarily organic) were tested (Marvin in Sykes, 1965). The 32 chemicals meeting the requirements were further tested for effects on various marine life and for reproducibility of results. Finally, only eight toxicants were acceptable. One cost $100 per gram; stocks of another were totally depleted by the tests and a new supplier could not be found. In addition, researchers found different reactions of the chemicals when using natural seawater instead of artificial culture media. They concluded that Florida coastal waters contained some agent that inhibited or neutralized toxicity of the chemicals tested.

Even if a selective, inexpensive chemical or physical mechanism were found to kill *G. breve* (and related food chain phytoplankters) the problem of treatment is immense. Lethal concentrations are not always detectable by discolored seawater. Visible red tide areas often cover 5 to 26 square kilometers (2 to 10 square miles) with discoloration ranging from a milky green to a brownish-red. As one visible area was treated, *G. breve* would be reconcentrated by winds, currents, and density gradients. The effort would therefore require initial treatment and continual retreatment. Finally, *G. breve* toxin is only released when the cells rupture. Consequently, destroying *G. breve* can in itself cause fish kills.

Many people recognize the obvious drawbacks of chemical and physical controls, but not those of biological controls. Biological control involves seeding the affected area with either 1) a dinoflagellate that would compete for space and available nutrients, 2) a pathogen such as a virus that would attack *G. breve* cells, or 3) a predator capable of devouring massive quantities of the red tide organism. Finding a specific competitor for *G. breve* would be difficult, particularly since it appears that *G. breve* produces an inhibitory metabolite. Introducing pathogens is a dangerous alternative, because their effects on the total marine community are not yet properly understood. Problems with introducing predators are at least partially the same as those with introducing pathogens. Moreover, culturing a predator in the amounts needed would be an impossible task if the animals had to be kept alive. Some researchers speculate that if the organisms could be frozen, dehydrated and stored, a supply could be accumulated over several years. Unfortunately, this supply would be depleted in the first hours of treatment. For example, if a selected predator consumed 1,000 *G. breve* cells per day, a 13-square-kilometer (5 square miles) red tide patch, having an average count of 2 billion *G. breve* cells per cubic meter, would require about 26 trillion predators for treatment to a depth of only 1 meter. Now, if we could culture 1 million predators per 5 gallon container every two weeks, using 100,000 containers or perhaps ponds accommodating 500,000 gallons of seawater, it would take 10 years to grow enough predators just to treat that 13-square-kilometer red tide area.

If one parameter favorable to red tides could be eliminated or modified prior to an outbreak, then red tides might be prevented or controlled before the organisms reached lethal concentrations or populated extensive areas. In addition, if a resident cyst population of *G. breve* is found to exist in coastal sediments, a method might be developed to retard excystment during favorable conditions. However, in all probability such an approach would involve extensive treatment, perhaps year-round, and be very costly.

Since historical records indicate that red tides are natural and common occurrences along the Florida west coast, these outbreaks must contribute to the ecological structure of this area. Consequently, some environmentalists question whether control should be attempted (even if feasible) until the role of red tide in the ecosystem is better understood. There is yet another consideration: fishermen report that shrimp catches in the year following a significant red tide are usually higher than average. Additional research should be conducted to substantiate such reports.

Considering past research results, the Department of Natural Resources feels that further investigations should not emphasize control. Instead, a much more thorough understanding of this phenomenon and its role in the total ecosystem should be obtained.

PRESENT RESEARCH

Past red tide research conducted by state and federal agencies and various universities has resulted in numerous pertinent observations and publications concerning *G. breve* blooms. Research conducted or supported by the Florida Department of Natural Resources has provided information on: 1) morphological variability of the causative organism, 2) nutrients best supporting its growth, 3) nutrients or growth factors as limiting agents, 4) time required for detoxification of oysters in nature, and 5) physical and chemical parameters necessary for initiation and maintenance of *G. breve* blooms. This research has resulted in two suggested methods of red tide prediction. More recent research, much of it supported by federal grants to universities, has concentrated on characterization of chemical, physical, and physiological aspects of the toxin(s).

Present State research is directed toward practical evaluation. Studies include:

1. Verifying existence of cyst populations,
2. Investigating susceptibility of certain invertebrates, particularly gastropods, to *G. breve* toxin,
3. Field studies investigating why bottom fishes are killed first during red tides, supplemented by laboratory studies testing varying susceptibility among different species or their life stages with different size or behavior characteristics,
4. Determining site of toxin assimilation in fish and investigating susceptibility of fertilized fish eggs, larvae, and juveniles,
5. Investigating significance of blue-green algal blooms preceding red tides,
6. Determining toxin storage site in shellfish such as oysters and clams,
7. Determining extent of damage directly attributable to *G. breve* toxin in comparison to secondary damage caused by oxygen depletion and associated stress conditions, and
8. Investigating extent of red tide effects (primary and secondary) on offshore reefs.

ACKNOWLEDGMENTS

We thank W. G. Lyons and B. S. Roberts for editorial assistance. R. M. Ingle, past Chief of the Bureau of Marine Science and Technology, deserves special acknowledgment for his interest and involvement in red tide research over the past 20 years.

PERTINENT REFERENCES

ALDRICH, D.

1960. Physiology of the Florida red tide organism, p. 40-42. *In* Fishery research Galveston Biological Laboratory, fiscal year 1960. U.S. Fish Wildl. Serv., Circ. 92.

BRONGERSMA-SANDERS, M.

1948. The importance of upwelling water to vertebrate paleontology and oil geology. Kon. Ned. Ak. Wet., Verh. Afd. Nat. (Tweede Sectie) 45(4): 1-112.

BRONGERSMA-SANDERS, M.

1957. Mass mortality in the sea, p. 941-1010. *In* J. Hedgepeth [ed.], Treatise on marine ecology and paleoecology, Vol. 1. Geol. Soc. Am. Mem. 67.

BRYDON, G.A., D.F. MARTIN, and W.K. OLANDER

1971. Laboratory culturing of the Florida red tide organism, *Gymnodinium breve.* Environ. Lett. 1(4): 235-244.

CHEW, F.

1955. Red tide and the fluctuation of conservative concentrations at an estuarine mouth. Bull. Mar. Sci. Gulf Caribb. 5(4): 321-330.

CHEW, F.

1955. On the offshore circulation and a convergence mechanism in the red tide region off the west coast of Florida. Trans. Am. Geophys. Union 36(6): 963-974.

COLLIER, A., W.B. WILSON, and M. BORKOWSKI

1969. Responses of *Gymnodinium breve* Davis to natural waters of diverse origin. J. Phycol. 5(2): 168-172.

CUMMINS, J. and A. STEVENS

1970. Investigations of *Gymnodinium breve* toxins in shellfish. U.S. Dep. Health Educ. Welfare Pub. Hlth. Serv. Bull. 74 p.

DAVIS, C.C.

1948. *Gymnodinium brevis* sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. Bot. Gaz. 109(3): 358-360.

DOIG, M.T., III and D.F. MARTIN

1972. Physical and chemical stability of ichthyotoxins produced by *Gymnodinium breve.* Environ. Lett. 3(4): 279-288.

DRAGOVICH, A.

1967. Morphological variations of *Gymnodinium breve* in situ. Q. J. Fla. Acad. Sci. 30(4): 245-249.

FLORIDA BOARD OF CONSERVATION

1964. A collection of data in reference to red tide outbreaks during 1963. Fla. Board Conserv. Mar. Lab., Prelim. Rep. 125 p.

FLORIDA BOARD OF CONSERVATION

1966. Observations of an unusual red tide. A symposium. Fla. Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 8. 84 p.

GALTSOFF, P.S.

1948. Red tide. Progress on the investigations of the cause of mortality of fish along the west coast of Florida conducted by the Fish and Wildlife Service and cooperating organizations. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 46: 1-44.

GUNTER, G.

1957. Temperature, p. 159-184. *In* J. Hedgepeth [ed.], Treatise on marine ecology and paleoecology, Vol. 1. Geol. Soc. Am. Mem. 67.

GUNTER, G., R.H. WILLIAMS, C.C. DAVIS, and F.G.W. SMITH

1948. Catastrophic mass mortality of marine animals and coincident phytoplankton blooms on the west coast of Florida, November 1946 to August 1947. Ecol. Monogr. 18(3): 309-324.

HELA, I.

1955. Ecological observations on a locally limited red tide bloom. Bull. Mar. Sci. Gulf Caribb. 5(4): 269-291.

HELA, I.

1956. A pattern of coastal circulation inferred from synoptic salinity data. Bull. Mar. Sci. Gulf Caribb. 6(1): 74-83.

HUTTON, R.F.

1956. An annotated bibliography of red tides occurring in the marine waters of Florida. Q. J. Fla. Acad. Sci. 19(2-3): 123-146.

INGLE, R.M. and D.P. de SYLVA

1955. The red tide. (Revision of 1948). Fla. State Board Conserv. Educ. Ser. No. 1. 30 p.

INGLE, R.M. and D.F. MARTIN

1971. Prediction of the Florida red tide by means of the iron index. Environ. Lett. 1(1): 69-74.

INGLE, R.M. and J. WILLIAMS

1966. Introduction to a northeast Gulf of Mexico red tide, p. 1-8. *In* Observations of an unusual red tide. A symposium. Fla. Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 8.

LACKEY, J.B. and J.A. HYNES
1955. The Florida Gulf coast red tide. Engng. Progr. Univ. Fla. 9(2): 3-23.

LACROSSITT, H.
1954. The truth about Florida's red tide. Sat. Eve. Post 227(7): 28-29, 67-68.

MARTIN, B.B., D.F. MARTIN, and G.M. PADILLA
1972. Hemolytic assay of oysters for *Gymnodinium breve* toxin. Environ. Lett. 2(4): 239-244.

MARTIN, D.F. and A. CHATTERJEE
1970. Some chemical and physical properties of two toxins from the red tide organism, *Gymnodinium breve.* U.S. Fish Wildl. Serv., Fish. Bull. 68(3): 433-443.

MARTIN, D.F., M. DOIG, III, and R. PIERCE, JR.
1971. Distribution of naturally occurring chelators (humic acids) and selected trace metals in some west Florida streams, 1968-1969. Fla. Dep. Nat. Resour. Mar. Res. Lab., Prof. Pap. Ser. No. 12. 52 p.

McFARREN, E.F., H. TANABE, F.J. SILVA, W.B. WILSON, J.E. CAMPBELL and J. H. LEWIS
1965. The occurrence of a ciguatera-like poison in oysters, clams and *Gymnodinium breve* cultures. Toxicon 3:111-123.

MOE, M.A., JR.
1963. A survey of offshore fishing in Florida. Fla. Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 4. 117 p.

MORTON, R.A. and M.A. BURKLEW
1969. Florida shellfish toxicity following blooms of the dinoflagellate *Gymnodinium breve.* Fla. Dep. Nat. Resour. Mar. Res. Lab., Tech. Ser. No. 60. 26 p.

OLANDER, K.A.
1968. The effect of some selected metal ions on the growth of *Gymnodinium breve.* Master's Thesis, Univ. South Florida, Tampa.

POMEROY, L.R., H.H. HASKIN, and R.A. RAGOTZKIE
1956. Observations on dinoflagellate blooms. Limnol. Oceanogr. 1(1): 54-60.

PRAKASH, A., J.C. MEDCOF, and A.D. TENNANT
1971. Paralytic shellfish poisoning in eastern Canada. Fish. Res. Board Can. Bull. 177. 87 p.

QUAYLE, D.B.
1969. Paralytic shellfish poisoning in British Columbia. Fish. Res. Board Can. Bull. 168. 68 p.

RAY, S.M.

1972. Paralytic shellfish poisoning: a status report, p. 171-199. *In* T.C. Cheng [ed.], Current topics in comparative pathobiology, Vol. 1. Academic Press, New York.

RAY, S.M. and D. ALDRICH

1967. Ecological interactions of toxic dinoflagellates and molluscs in the Gulf of Mexico, p. 75-83. *In* F. Russell and P. Saunders [eds.], Animal toxins. Pergamon Press, New York. York.

ROUNSEFELL, G.A. and A. DRAGOVICH

1966. Correlation between oceanographic factors and abundance of the Florida red tide (*Gymnodinium breve* Davis), 1954-1961. Bull. Mar. Sci. Gulf Caribb. 16(3): 404-422.

ROUNSEFELL, G.A. and W.R. NELSON

1966. Red tide research summarized to 1964 including an annotated bibliography. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 535. 85 p.

RYTHER, J.H.

1955. Ecology of autotrophic marine dinoflagellates with reference to red water conditions, p. 387-414. *In* F.H. Johnson [ed.], The Luminescence of Biological Systems. Am. Assoc. Adv. Sci., Washington, D.C.

SASNER, J.J., JR.

1965. A study of the effects of a toxin produced by the Florida red tide dinoflagellate, *Gymnodinium breve* Davis. Ph.D. dissertation, University of California, Los Angeles.

SELIGER, H.H., J.J. CARPENTER, M. LOFTUS, and W.D. McELROY

1970. Mechanisms for the accumulation of high concentrations of dinoflagellates in a bioluminescent bay. Limnol. Oceanogr. 15(2): 234-245.

SIEVERS, A.M.

1969. Comparative toxicity of *Gonyaulax monilata* and *Gymnodinium breve* to annelids, crustaceans, molluscs and a fish. J. Protozool. 16(3): 401-404.

SLOBODKIN, B.L.

1953. A possible initial condition for red tides on the coast of Florida. J. Mar. Res. 12(1): 148-155.

SMITHSONIAN INSTITUTION, CENTER FOR SHORT-LIVED PHENOMENA

1971. Annual report, 1970. Smithson. Inst. Short-lived Phenom. 296 p.

SPIKES, J.J.
1971. Extraction, concentration and biologic effects of a toxic material from *Gymnodinium breve* toxin. Ph.D. dissertation, University of Texas, Medical Branch (Galveston). 112 p.

SPRINGER, V.G. and K.D. WOODBURN
1960. An ecological study of the fishes of the Tampa Bay area. Fla. State Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 1. 104 p.

STEIDINGER, K.A.
1972. Phytoplankton, p. III F-1 — III F-17. *In* A summary of knowledge of the eastern Gulf of Mexico, 1972. Coordinated by the State University System of Florida's Institute of Oceanography under a May 1972 American Petroleum Institute contract.

STEIDINGER, K.A., M.A. BURKLEW, and R.M. INGLE
1973. The effects of *Gymnodinium breve* toxin on estuarine animals, p. 179-202. *In* D. Martin and G. Padilla [eds.], Marine pharmacognosy. Academic Press, New York.

STEIDINGER, K.A., J.T. DAVIS, and J. WILLIAMS
1967. Dinoflagellate studies on the inshore waters of the west coast of Florida, p. 4-47. *In* Red Tide studies, Pinellas to Collier Counties, 1963-1966. Fla. Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 9.

STEIDINGER, K.A. and R.M. INGLE
1972. Observations on the 1971 summer red tide in Tampa Bay, Florida. Environ. Lett. 3(4): 271-277.

STEIDINGER, K.A. and J. WILLIAMS
1970. Memoirs of the Hourglass Cruises: Dinoflagellates. Fla. Dep. Nat. Resour. Mar. Res. Lab., Vol. II. 251 p.

SYKES, J.E.
1965. Bureau of Commercial Fisheries symposium on red tide. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 521: 11 p.

TORPEY, J. and R.M. INGLE
1966. The red tide. (Revision of 1955.) Fla. Board Conserv. Mar. Lab., Educ. Ser. No. 1. 27 p.

UNIVERSITY OF MIAMI MARINE LABORATORY
1954. Red tide studies. Preliminary report, January to June 1954, to Florida State Board of Conservation, No. 54-19. 117 p (mimeo).

WILLIAMS, J. and R.M. INGLE

1972. Ecological notes on *Gonyaulax monilata* (Dinophyceae). Fla. Dep. Nat. Resour. Mar. Res. Lab., Leaf. Ser. Vol. I, Pt. 1, No. 5. 12 p.

WILSON, W.B.

1966. The suitability of seawater for the survival and growth of *Gymnodinium breve* Davis, and some effects of phosphorus and nitrogen on its growth. Fla. Board Conserv. Mar. Lab., Prof. Pap. Ser. No. 7. 41 p.

WILSON, W.B.

1967. Forms of the dinoflagellate *Gymnodinium breve* Davis, in cultures. Contrib. Mar. Sci. 12: 120-134.

WILSON, W.B. and S.M. RAY

1956. The occurrence of *Gymnodinium breve* in the western Gulf of Mexico. Ecology 36(2): 388.

WOODCOCK, A.H.

1948. Note concerning human respiratory irritation associated with high concentrations of plankton and mass mortality of marine organisms. J. Mar. Res. 7(1): 56-62.

APPENDIX

G. BREVE MEDIA CONCENTRATIONS IN PPM (MG/LITER)

Table Values from Olander, 1968

Name	Formula	Concentration *B-5	 **NH-15
Ammonium Chloride	NH_4Cl	1.0	1.0
Ammonium Vanadate	$NH_4\ VO_3$	—	0.025
Barium Chloride	$BaCl_3$	—	0.05
Biotin		0.0005	0.001
Boric Acid	H_3BO_3	—	0.25
Calcium Chloride	$CaCl_2$	—	700.0
Disodium ethylenediaminetetracetate (EDTA)		50.0	10.0
Ferric Chloride	$FeCl_3$	0.02	0.25
Magnesium Chloride	$MgCl_2 \cdot 6H_2O$	—	4,500.0
Magnesium Sulfate	$MgSO_4 \cdot 7H_2O$	0.2	6,000.2
Manganese Chloride	$MnCl_2$	—	0.05
Potassium Chloride	KCl	—	600.0
Potassium Chromate	K_2CrO_4	—	0.01
Potassium Nitrate	KNO_3	—	10.0
Potassium Phosphate, Dibasic	K_2HPO_4	0.5	10.5
Sodium Bicarbonate	$NaHCO_3$	1.0	1.0
Sodium Chloride	$NaCl$	—	24,000.0
Sodium Silicate	Na_2SiO_3	—	0.25
Sodium Sulfide	$Na_2S \cdot 9H_2O$	3.5	0.5
Thiamine Hydrochloride		10.0	10.0
†Titanium Trichloride	$TiCl_3$	—	0.25
Tris (hydroxmethyl) aminomethane (Tris)	$H_2NC(CH_2OH)_3$	—	400.0
Vitamin B_{12}		0.001	0.001
Zirconyl Chloride	$ZrOCl_2$	—	0.10

*Basis of B-5 medium is natural seawater

**Basis of NH-15 medium is triple-distilled water

†Collier et al., 1969