VIII. Introduction to harmful red tides in Texas waters

Apart from brown tides, red tides comprise the other common harmful algal bloom in Texas coastal waters. Red tides are caused by blooms of dinoflagellates that at high densities can produce colors from yellow to reddish-brown in the water. The cells are attracted to light and actively swim toward the surface where they may be concentrated to high densities by wind, currents and tides (Tester and Fowler, 1990). No more than twenty dinoflagellate species are thought to be toxic (Steidinger, 1979), providing sources of poisonous compounds that during a bloom that can cause mass mortalities of marine organisms and can lead to human health problems when contaminated seafoods are consumed or aerosol toxins are inhaled. Toxic red tide blooms occur throughout the world but are relatively rare in Texas coastal waters. So far, there have been two species of dinoflagellates responsible for toxic red tides in Texas: the unarmored *Gymnodinium breve* (formerly *Ptychodiscus brevis*) and *Alexandrium* (formerly *Gonyaulax*) *monilata*, an armored, chain-forming species. Typically, *Gymnodinium breve* first blooms in the Gulf of Mexico at least several miles off the coast. Currents may move these blooms to shore and/or into coastal bays, and bloom concentrations can persist from one week to several months. Blooms may be confined to a particular bay or estuary (typical of *A. monilata*) or may spread to cover a massive area of coastal waters and embayments (as with *G. breve*). The toxins in both of these dinoflagellate species can cause extensive mortality in fish and invertebrates, but in Texas, only *Gymnodinium breve* red tides have been reported to cause human health problems in the forms of temporary respiratory irritation from aerosol toxin and neurotoxic shellfish poisoning (NSP). The toxin commonly becomes an aerosol when cells are ruptured by wave action, as in heavy surf, with toxin or toxin-laced cell fragments carried into the air with water vapor and/or minute salt particles. NSP results from consuming raw or cooked oysters, clams or mussels contaminated with what is commonly called "brevetoxin." The symptoms, including nausea, dizziness and tingling in the extremities, go away in a few days; no deaths have been reported due to NSP (Steidinger, 1983).

Both *Alexandrium monilata* and *Gymnodinium breve* undergo sexual as well as asexual reproduction. The possibility that blooms initiate in these red tide species from benthic resting cysts known as hypnozygotes is likely, though the factors that trigger excystment of the hypnozygotes are yet unknown. The sexual cycle in *A. monilata* involves production of two motile, isogamous, haploid gametes from each single haploid asexual cell. The fusion of two gametes produces first a double-flagellated, diploid planozygote, then a hypnozygote; excystment releases one cell that soon divides asexually into a small chain of four, but whether meiosis re-establishes haploidy before or after excystment is not known (Walker and Steidinger, 1979). The *G. breve* sexual cycle is similar. Haploid cells form isogamous gametes which, upon pairing and fusion, produce diploid planozygotes (Walker, 1982). In the same study, Walker was unable to induce hypnozygotic cyst formation from the planozygotes, and to date, neither laboratory cultures nor sediment analyses have documented the existence of *G. breve* hypnozygotes (K. A. Steidinger, pers. comm.).

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IX. Historical trends of Texas red tides

Red tides appear to be infrequent events in the CCBNEP area. Preliminary investigations indicate that only four *Gymnodinium breve* and six or seven *Alexandrium monilata* blooms have been documented along the entire Texas coast since the major red tide of 1935 (Snider, 1987; the ambiguity regarding the number of *A. monilata* red tides stems from the non-published sources of information available to Snider). Whereas *G. breve* blooms have been relatively well-studied, given the extent of their negative impact on fish and shellfish in Texas and their frequent recurrence off West Florida, *A. monilata* blooms, which have not contaminated shellfish, have not been so well-documented. Before the apparent 1935 red tide, the relationship between fish kills and dinoflagellate blooms was not completely understood, making the causes of fish kills difficult to determine prior to that time.

A. Frequency

1. Offshore blooms of *Gymnodinium breve* in Texas

The mass mortality of fishes from the end of June to mid-September of 1935 along the South Texas coast was not documented as linked to a dinoflagellate bloom (Lund, 1936; *cf*. Steidinger and Joyce, 1973), but, given Lund's report of an associated aerosol irritant ("irritating 'gas'") in the absence of a positive species identification, this bloom was almost certainly due to *G. breve* (Snider, 1987). Newspaper reports at the time indicate that local scientists varied in their opinion of the cause of the fish kill. Dr. E.J. Lund of the University of Texas blamed it on low salinity waters along the coast, while Dr. C.J. Reed of Texas A&I University blamed it on a bloom of diatoms which was clogging the gills of fish and causing them to suffocate. Local fishermen suspected that canisters of poison gas left over from the First World War were finally decomposing and releasing their deadly fumes. Others suspected release of gases associated with volcanic activity (Corpus Christi Caller times, Houston Chronicle, Houston Post, and San Antonio Evening News).

Whereas two to three other suspected red tide blooms occurred in Texas waters within the two decades after 1935 (Gunter, 1951), the next major bloom occurred in September of 1955. As indicated by fish mortality, the bloom ranged from 18 miles north of Port Isabel to the coastal waters of the adjacent Mexican coastal state of Tamaulipas. Highest reported densities of the causative species, *G. breve*, were found 36 miles south of the Rio Grande River mouth at $\geq$22,000 cells/ml (Wilson and Ray, 1956). Wilson and Ray (1956) offer no indication that the bloom originated in Texas waters and proceeded south or vice versa, though their short publication does imply a Texas origin.

The red tide of 1974 is the poorest documented of the four major bloom events in South Texas. The *Port Isabel/South Padre Press* on 10 October 1974 reported that the bloom was sighted south and east of Brownsville/Matamoros some 150 miles off the coast, causing a massive fish kill that eventually littered Mexican beaches, but gave no indication of its duration. The causative organism was not identified, but may well have been *Gymnodinium breve*.

This major *Gymnodinium breve* bloom lasting from the end of August to late October of 1986 is arguably the worst yet experienced along the Texas coast with effects stretching from its inception near Galveston Island to Mexico. Along Mustang Island Beach alone, investigators estimated 100,000 dead fish per linear mile over 14 miles of beach; the Rockport harbor boat basin produced water samples with up to 1.1 million *G. breve* cells/ml, concentrations almost certainly due to physical factors such as wind-driven currents (Trebatoski, 1988).

2. Inshore blooms of *Gymnodinium breve* in Texas

There has been one prominent *G. breve* bloom in inshore waters. On 16 December 1990, the *Brownsville Herald* newspaper began a series of reports on water sampling by health and marine officials in the Brownsville Ship Channel in response to a previous fish kill in November, and though the newspaper was not specific, the suspected causative organism was identified by Dr. Eleanor Cox at Texas A & M as *Gymnodinium breve* (Roy Lehman, pers. comm.). While the ship channel remained closed to shellfishing, *G. breve* concentrations apparently dropped below detection level shortly before the *Herald*'s final report on this red tide on 12 April 1991. According to records from the Shellfish Sanitation Division of the Texas Department of Health, there have been problem concentrations of *G. breve* at other times and places forcing closure of shellfish beds, yet most of these blooms seem to have escaped wider notice. For instance, from 25 August to 2 September 1990, Aransas and Copano Bays were closed to shellfish harvesting due to a short-lived *G. breve* bloom (see Table 4 in Section III. E.). Table 4 highlights some of the more prominent commercial harvesting areas affected by the closure and reopening of their shellfish beds. Though the low frequency of major offshore blooms suggests that conditions favorable for initiation do not commonly occur in South Texas waters, the many closures of shellfish beds by the Texas Department of Health imply that *G. breve* blooms occur with greater frequency than is commonly realized (G. Heideman, pers. comm.). Table 1 offers further support for more frequent blooms by listing selected dates on which shellfish meats from various Texas bays caused the death of one or more mice used in the brevetoxin bioassay. The dates in Table 1 were selected because they do not coincide with the durations of the well-documented *G. breve* red tides discussed throughout this report and because they may represent a higher frequency of bloom concentrations largely unnoticed except by the Shellfish Sanitation Division of the Texas Department of Health.

Table 1. Selected Texas bays with prominent commercial shellfish beds matched with dates on which samples of shellfish meats proved fatal to one or more mice in the brevetoxin bioassay used by the Texas Department of Health. (Data courtesy of G. Heideman, Texas Department of Health.)

Matagorda	Espiritu Santo	San Antonio	Copano	Corpus Christi	Nueces	South
3/3/87 6/24/87 8/14/87	3/4/87	2/15/87 3/4/87	4/1/87	4/2/87 8/17/87	4/2/87 8/17/87 1/27/88 8/18/88	3/6/91

3. Comparative frequencies of *G. breve* blooms

Simply determining the average frequency of *Gymnodinium breve* red tides from the four major offshore blooms gives a rough mean occurrence of one major bloom off the Texas coast every 17 years with a standard deviation of 3 to 4 years. When compared to a recent detailed list of apparent *G. breve* red tides off the southern West Florida coast, blooms or near blooms were reported in a total of 65 months from 1975-1991 with 46% of those reports occurring in September, October and November (Abdelghani, 1994; Figure 1).

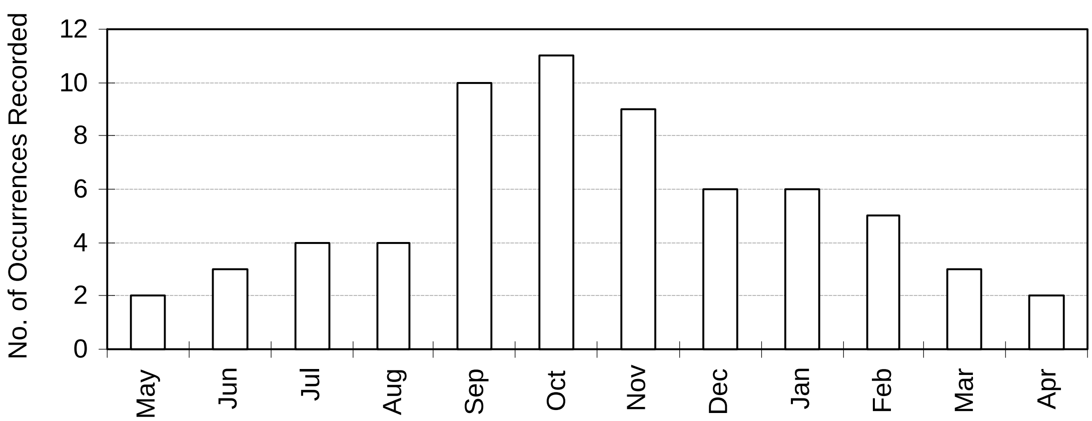

FIGURE 1. Cumulative recorded occurrences per month of Gymnodinium breve blooms from 1975-1991 in West Florida (Data from Abdelghani, 1994)

What Abdelghani's (1994) unpublished draft report does not indicate is whether any mortality was associated with any report of higher than normal *G. breve* concentrations in that span of time; shellfish harvesting areas were closed on at least several occasions. Rounsefell and Nelson (1966) found records of 17 toxic red tides on Florida's west coast between 1844 and 1960; the adjective "toxic" may imply marine mortality. Joyce and Roberts (1975) state that about 30 red tides occurred in Florida waters between 1844 and 1974, an average of one every four to five years, but they make no mention of mortality and can only attribute those since 1946 to *G. breve*. One may easily calculate that about 13 red tides occurred off West Florida between 1960 and 1974, but whether that comparatively high rate is due to an increase in bloom events or improved detection is debatable (Hallegraeff, 1993; Anderson, 1994). For further comparison, Gunter (1951) reported that red tide-induced mortalities of marine life along the West Florida coast tended to occur once every 10 years on average with delays of up to 30 years, far more similar to the Texas experience.

4. *Alexandrium monilata* blooms in Texas

Documentation of *Alexandrium monilata* blooms in Texas is less available than that for *G. breve*. Connell and Cross (1950) discussed the correlation of mass mortality of fish with a 1949 episode of red tide in Offats Bayou near Galveston. Such summer fish kills had been documented in the bayou from 1936 to 1941 by Gordon Gunter, and local fishermen, who claim that summer mortality had been an almost annual occurrence since as early as 1929. The organism Connell and Cross (1950) described occurred in chains and was similar but not identical to *Gonyaulax catenella*. Using samples mainly from the Indian and Banana Rivers on Florida's east coast, Howell (1953) described a small dinoflagellate species known to form chains of up to 40 cells in length, and in early September of 1952, Howell found identical chain-forming dinoflagellates in a sample taken from Offatts Bayou. Whereas there was some debate over the proper generic classification at the time, what Connell and Cross (1950) and Howell (1953) described as a *Gonyaulax* species is now known as *Alexandrium monilata*. There are reports of "annual" blooms in the East Lagoon of Galveston Island (Marvin, 1965; Proctor, 1965; Proctor, 1966; Ray and Aldrich, 1967) and two consecutive blooms offshore of Galveston in 1971-72 (Wardle, Ray and Aldrich, 1975). Since the 1971-72 blooms, *A. monilata* has not reappeared in bloom concentrations in the Galveston area (W. J. Wardle, pers. comm.), though local blooms have occurred in various parts of South Texas. Jensen and Bowman (1975) state that a colleague at the Texas Water Quality Board had documented an *A. monilata* bloom and fish kill in the Viola Turning Basin of the Corpus Christi Inner Harbor in the fall of 1972. An *A. monilata* bloom reappeared in the Viola Turning Basin in the summer of 1975, first detected by routine monitoring at what became the maximum recorded concentration of 5.14 million cells/liter (Jensen and Bowman, 1975).

B. Duration

1. *Gymnodinium breve*

The *G. breve* red tide of 1935 was detectable from 30 June to 13 August, the first report coming from Padre Island and the last from the coast at the northern tip of Matagorda Bay, a total of 45 days (Lund, 1936). The apparent 1955 *G. breve* red tide lasted for more than 12 days in September, but Wilson and Ray (1956) do not specify when the fish kill was first noticed nor when fish mortality ceased off the Tamaulipas Coast of Mexico. No duration could be determined for the 1974 red tide 150 miles offshore and southeast of Brownsville. The Brownsville Inner Harbor bloom of *G. breve* reported by Jensen and Bowman (1975) began to recede after about two months but lingered for perhaps two more months. The Coast Guard first noted the 1986-87 red tide as what appeared to be an oil slick washing ashore at the southern tip of

Galveston Island on 27 August 1986; the subsequent large-scale event ceased 57 days later (Trebatoski, 1988). Trebatoski (1988) also noted that a dense, isolated recurrence appeared on 8 January 1987 in Corpus Christi Bay but apparently did not persist past 4 February (Texas Department of Health). In comparison, the implied duration of reported red tide bloom concentrations (apparently all *G. breve*) along the West Florida coast from 1975-1991 ranged from "brief" to approximately seven months, the latter in 1980 (Abdelghani, 1994).

2. *Alexandrium monilata*

The 1972 *A. monilata* bloom in the Viola Turning Basin of the Corpus Christi Inner Harbor lasted from August to September; the 1975 resurgence of *A. monilata* in the same location persisted from July to September (Jensen and Bowman, 1975). During the 1975 bloom, cell counts and the number and length of *A. monilata* chains generally decreased throughout the inner harbor until no longer detectable on 17 September, but a fish kill did occur in the turning basin on 22 August, despite the small concentrations of *A. monilata* detected there at that time (Jensen and Bowman, 1975).

C. Environmental effects

1. Commercial

The most immediate negative economic impact of red tide blooms is fish and invertebrate mortality. Aquaculture projects are especially susceptible to the toxins by virtue of stock density and potentially catastrophic loss of investment (Steidinger and Vargo, 1988; Shumway, 1990). Two experimental studies with both *Gymnodinium breve* and *Alexandrium monilata* illustrate the probable impact of the respective toxins on organisms of commercial value in the field. Sievers (1969) exposed several kinds of marine animals to concentrations of *G. breve* and *A. monilata* cultures from undiluted to 90% dilution over 48 hours to determine the comparative toxicity of each in terms of mortality. Fish were quite sensitive to both toxins (especially so to *G. breve* toxin), crustaceans were resistant to both, and both annelids and mollusks were more sensitive to *A. monilata* toxin, including the American oyster (*Crassostrea virginica*) and a mussel (*Brachidontes recurvus*). The oysters and mussels immediately failed to open upon exposure to lower dilutions of *A. monilata* cultures and suffered high mortality in undiluted cultures. Ray and Aldrich (1967) indicate that such mortality may arise simply because the bivalves cannot maintain shell closure well past 24 hours. In their 24-hour laboratory study, oysters remained tightly closed almost constantly while in *A. monilata* cultures. Chicks were not poisoned by ingestion of the oyster homogenate, even when the homogenate was combined with actual *A. monilata* cells or prepared from oysters exposed to an *in situ* bloom of *A. monilata*. In the same study, three of four oysters exposed to *G. breve* cultures filtered and consumed cells after some delay in opening; five grams of the subsequent oyster homogenate force-fed to each of four chicks proved fatal to all within 24 hours.

In 1971 and 1972, *A. monilata* blooms occurred not far offshore of Galveston, producing high numbers and a wide variety of dead and dying marine organisms, including the commercially important blue crab, *Callinectes sapidus* (both years), the stone crab, *Menippe mercenaria* (both years), and the oyster, *Crassostrea virginica* (1972 only; Wardle *et al*., 1975). Though the findings of Wardle *et al*. (1975) indicate that crustaceans are not immune to mortality induced by *A. monilata* blooms, other dinoflagellate toxins (including brevetoxin) are not known to cause mortality or contaminate the meat, so crabs, shrimp and lobsters are marketable even at the height of toxic blooms (Roberts *et al*., 1979, *re* brevetoxin; Shumway, 1990).

Edible bivalve mollusks are another matter, and the public health implications of contaminated bivalve meats can close lucrative fisheries temporarily, on a seasonal basis or indefinitely. Shumway (1990) reviews sources that document a worst-case scenario in Alaska. With tens of thousands of miles of coastline and over 100 clam species, the Alaskan clam industry produced millions of pounds of shellfish products until it was forced to close permanently shortly after World War II because of toxic red tide problems. When the Gulf Stream transported *G. breve* cells or cysts from West Florida to the Carolinas in 1987, the resultant bloom closed shellfish beds for the first time in North Carolina's history and caused losses of $20 million (Anderson, 1994). Efficient monitoring programs, however, enable some shellfish aquaculture efforts to continue safely in spite of recurrent blooms, exemplified by successful mussel cultures in the northeastern United States and in the Japanese scallop industry (Shumway, 1990); this may be the only way to effectively reduce the negative economic impact of toxic dinoflagellates on bivalve fisheries.

The remaining problem for shellfish beds exposed to *G. breve* blooms is the necessary ban on harvesting for up to two months or until tests indicate that the meat is no longer toxic (Steidinger and Ingle, 1972). In 1990, Tester and Fowler pointed out that the U. S. Food and Drug Administration's interpretation of the American Public Health Association guidelines regarding an acceptable amount of NSP in shellfish contaminated by *G. breve* was more conservative than that for shellfish contaminated with the potentially lethal PSP toxin (paralytic shellfish poisoning, caused by numerous other dinoflagellate species). In spite of their recommendation that the acceptable amount of NSP toxin in shellfish be equated with that for PSP toxin, given the more than acceptable public health risk in doing so (Tester and Fowler, 1990), the FDA to date has not acted upon that recommendation (P. A. Tester, pers. comm.). In effect, the overly conservative restriction increases the negative economic impact produced by *G. breve* blooms on the shellfish industry by keeping shellfish beds closed for longer periods than truly necessary.

Steidinger and Vargo (1988) also cite adverse impacts on tourism, real estate and seafood sales in areas suffering from *G. breve* red tides. Jensen (1975) discussed the economic impact as not just a problem for the affected area but in surrounding states as well because of the "halo effect." His example was the *G. tamarensis* (PSP) red tide of 1972 in New England. The affected New England states quickly banned harvest and shipment of their shellfish, but despite the fact that no blooms affected New York waters, many citizens of that state responded irrationally by refusing to buy New York lobster, shellfish and finfish, avoiding Long Island seafood restaurants and causing a drop in the wholesale price for clams harvested from unaffected areas. Jensen (1975) concludes that, if necessary an efficient means exist with which governmental agencies can quickly note the occurrence and distribution of red tide blooms, what remains is for the seafood industry and the government to stem rumors and counteract misinformation with accurate and current facts about any toxic blooms, curtailing the "halo effect" that needlessly increases the scale of the negative economic impact.

Both *A. monilata* and *G. breve* possess icthyotoxins that threaten game and food fish populations in the Gulf of Mexico. Using juvenile mullet (*Mugil cephalus*) as their bioassay, Gates and Wilson (1960) noted mortality within 4.5 hours in all aliquots of *in vitro* cultures of *A. monilata* (some aliquots containing cells and/or cell fragments and others not) except the uninoculated control medium. Quick and Henderson (1975) did not completely list the fifteen species they necropsied during an extended *G. breve* red tide from October 1973 through June 1974 along the west coast of Florida, but mullet, ladyfish and anchovies were mentioned. Enormous numbers of fish of even greater sport or commercial value were estimated to have died as a result of the 1986 *G. breve* red tide along the Texas coast (Texas Parks and Wildlife Department, 1986; see Table 3.), including greater than 40,000 individuals each of red drum and southern flounder, about 80,000 spotted seatrout and more than 3.2 million Gulf menhaden. Riley *et al*. (1989) report that *G. breve* blooms can also reduce red drum recruitment during spawning periods; their source of red tide was the 1986 Texas bloom which achieved average peak densities of 7000 cells/ml with concentrations of almost 5×10^4 cells/ml in isolated patches in bays near Port Aransas throughout October. They showed that *G. breve* caused paralysis and death in laboratory-spawned and wild-caught red drum larvae at all concentrations above 40 cells/ml. Since both *A. monilata* and *G. breve* cause fish mortality, an extensive bloom of either can produce a corresponding loss of commercial and game species.

2. Public health

Shellfish contaminated with *Gymnodinium breve* cells or the heat stable toxin can produce neurotoxic shellfish poisoning (NSP) in people who consume raw or cooked meat. No paralysis occurs with NSP, but tingling of the skin (paresthesia), nausea, vomiting and some loss of voluntary muscle control (ataxia) are major symptoms occurring within the first three hours (Abdelghani, 1994). Contact dermatitis and/or conjunctivitus may occur in people immersed in water containing brevetoxin (Hemmert, 1975). An aerosol of either toxin-laced cell fragments or salt crystals released in surf zones can cause respiratory, skin and mucus membrane irritation, but the symptoms cease with no lasting effects once victims leave the area (Hemmert, 1975; Steidinger and Vargo, 1988). The temporary and mild effects of the aerosol toxin are fortunate since Pierce *et al*. (1990) determined that laboratory culture concentrations of *G. breve* could give rise to toxins enriched by 5 to 50 times in the aerosol relative to the culture. Though no deaths have yet been attributed to NSP (Shumway, 1990), people should not consume shellfish exposed to a *G. breve* bloom until reliable tests are conducted to ensure that the meat is no longer contaminated; this typically means a wait of one to two months after cessation of the bloom (Steidinger and Ingle, 1972).

Regarding brevetoxin itself, Baden and Thomas (1989) examined several different clones of *G. breve* and found significant variability in toxin content between *G. breve* populations experiencing different environmental conditions. Baden (pers. comm.) states that *G. breve* is very adept at performing the simple metabolic modifications that create variability in the toxin profile, and one may presume that the variability is due to different metabolic states within the organism. One should not, therefore, rule out the possibility that toxins from monoclonal *G. breve* populations, if such exist, could exhibit differential toxicity to marine animals and humans during a bloom depending on the bloom environment. Also, the 1990 studies by Pierce *et al.* and Roszell *et al.* revealed that six or more possible toxin profiles appear individually or in combination at different times in the life of a population, whether from examination of a monoclonal culture or a natural population. Taken together, these findings may indicate that one or more clones may exist in any given *G. breve* bloom population; regardless of the clonal constitution, a bloom may produce, as elements age within the population, a suite of toxins that varies in (1) the composition of toxic fractions, (2) the overall quantity of toxin released at any given point and/or (3) potency. The public health implications of these possibilities should be noted. Apparently no public health risks have yet been associated with the toxin of *Alexandrium monilata*.

3. Threats to endangered wildlife

Whereas red tide blooms may be detrimental to a variety of endangered species, very little documentation exists for adverse affects on, for example, marine mammals and sea turtles. The most likely and serious threat from red tide to such species in South Texas concerns the whooping crane.

The Aransas National Wildlife Refuge reported an overwintering population of 133 adult and 8 juvenile whooping cranes for early 1995. Given such low numbers, a *Gymnodinium breve* outbreak could be catastrophic for the entire flock (Tom Stehn, pers. comm.). The *G. breve* red tide of 1986-87 in South Texas came very close to infiltrating whooping crane critical habitat in the Aransas National Wildlife Refuge in the fall of 1986. Because clams, swallowed whole, comprise a small part of a whooping crane's diet in fall and early winter, brevetoxin could possibly sicken or kill any cranes consuming contaminated clams. Scaup and cormorants have been known to perish from exposure to brevetoxin in Florida, so the potential threat to the small population of endangered whooping cranes in South Texas calls for careful future monitoring (Stehn, 1987).

4. Ecosystem

The effects of *Gymnodinium breve* blooms on the ecosystem may be positive as well as negative. Both aspects are covered quite well by Steidinger and Vargo (1988), the source for much of what follows.

Obviously, negative ecosystem effects begin with marine organism mortality, whether due to toxin or oxygen depletion, whether affecting wild or cultured populations of marine life. Oxygen depletion by dense concentrations of either toxic or non-toxic red tide species can be as detrimental as toxins to fisheries or aquaculture; toxic blooms can cause problems as well for local, national and international economies, all discussed above.

Other ecosystem-level problems include (1) an undefined negative impact from excessive nutrient enrichment and bacteria concentrations in waters in which numerous fish carcasses decompose and (2) the influence of toxic dinoflagellates on other planktonic organisms. Regarding the latter, Freeberg *et al.* (1979) used medium in which *G. breve* had been grown as a medium for each of 28 phytoplankton species in axenic cultures. The medium significantly inhibited growth in 18 species, but its effect varied within species. The population levels of several diatoms and dinoflagellates and one flagellate barely increased above inoculum concentrations; two dinoflagellate inocula suffered lysis. Toxin extracts totally arrested growth in eight of twelve species (four diatoms and four dinoflagellates), but column chromotography could not separate the algal inhibition component from the ichthyotoxin. Huntley *et al.* (1986) used thirteen species of dinoflagellates as possible prey for two species of copepods in a large suite of experiments. Results of one experiment included *G. breve* as one of several dinoflagellates consistently rejected by the copepod *Calanus pacificus*; ingestion of *G. breve* cells produced elevated heart rate and loss of motor control in the copepod. The findings of Freeberg *et al.* (1979) and Huntley *et al.* (1986) counter the suggestion by Steidinger and Ingle (1972) that *G. breve* temporarily affects inshore and nearshore reef fisheries only, though Steidinger and Ingle (1972) may have had no data on smaller-scale effects.

In terms of the positive impacts *G. breve* has on ecosystems, Steidinger and Vargo (1988) point out that *G. breve*, like all known toxic dinoflagellates, are photosynthetic primary producers. As such, if a consumer can tolerate the toxin and digest the cellulose cell wall, *G. breve* can be a high quality food source. In addition, dinoflagellates in general tend to leak a variable percentage of their daily carbon in the form of amino acids and other complex biochemicals. In bloom proportions, contributions of the dinoflagellate population in terms of food for consumers, dissolved organics and the detritus of dead and dying cells must be large. Vargo *et al.* (1987) offers numerical estimates of various carbon production rates and estimates a high potential annual carbon input for *G. breve* blooms off West Florida based on several sources of data. At the time of publication, however, Steidinger and Vargo (1988) refer to Vargo *et al.* (1987) and only two other largely speculative studies on the supposed magnitude of the carbon contribution of any bloom species, but no subsequent studies have confirmed the significant carbon contribution postulated for *G. breve* blooms since 1988 (K. A. Steidinger, pers. comm.). Another possible positive result following the negative impact of a toxic bloom is that affected bottom communities are kept in states of simplified ecological interactions and increased system efficiency (Steidinger and Vargo, 1988). They cite several sources of support for the possibility that periodic fish and invertebrate kills from toxic red tides could make for communities less prone to catastrophic collapse from any major perturbation over the long term because their fauna and flora never have time to develop complex, fragile interdependencies. If this is true, the scientific community, the government, fishing industries and the public should best resign themselves to short-term toxic red tide problems in exchange for long-term benefits for affected benthic and reef communities and the commercially valuable resources harvested from them.

D. Possible causes

Steidinger and Vargo (1988) used the terms "initiation," "growth" and "maintenance" to categorize the various factors that produce and promote each stage in the progress of a red tide bloom, and they are used in this section as headings for discussing the causative factors for each stage in a *Gymnodinium breve* bloom. (The less problematical dinoflagellate *Alexandrium monilata* has not received as much attention in terms of published data on the factors prompting it to bloom.) Because multiple variables both known and unknown are at work in the marine environment during a bloom, any discussion of possible causes remains largely speculative. The causes of initiation in particular are problematical, for no proven catalyst has yet been found, whether a single variable or suite of variables. As a result, those factors discussed below as possible initiators for *G. breve* blooms definitely play roles in growth and maintenance as well (Rounsefell and Nelson, 1966; Steidinger and Haddad, 1981).

1. Initiation

In 1958, Collier suggested that a complex of biological factors causes a red tide bloom and that biologically active organic compounds are important to *G. breve*, including vitamin B12 and organic chelators, of which the latter can be supplemented or replaced by sulfides that commonly occur in West Florida estuaries.

On a more basic level, salinity is a principal factor in the initiation and subsequent progress of a *G. breve* bloom. Aldrich and Wilson (1960) determined that the optimal salinity range for axenic cultures of *G. breve* was from 27 to 37 ppt. Some organisms survived salinities as low as 22.5 and as high as 46.0 ppt for ten weeks, but the authors concluded that typical Gulf of Mexico salinities should not impose restrictions on the growth of this dinoflagellate, though water with salinities of 24 ppt or less should (see also Tester and Fowler, 1990). This low-salinity limitation helps explain why *G. breve* blooms commonly occur in oceanic rather than estuarine waters.

Along with favorable salinity levels, sufficient light and an adequate carbon source like carbon dioxide are necessary for any photosynthetic organism. Aldrich (1962) noted a correlation between red tide outbreaks involving *Gymnodinium breve* on the Florida Gulf coast and extended periods of heavy rainfall and subsequent organic input to the sea from river discharge. After unsuccessfully testing a multitude of organic substances as potential direct energy sources and discovering that the organism did not grow in the dark in spite of growth additives, he determined that *G. breve* was not heterotrophic and that sunlight and carbon dioxide were its principal growth requirements. He suggested that vitamins, trace metals and chelators from Florida river waters may facilitate photoautotrophy and thus bloom formation in *G. breve* (*cf.* Collier, 1958) and should be studied further.

Ten years later, Steidinger and Ingle (1972) included in their summary of information on *G. breve* red tides the facts that pollution does not catalyze blooms in Florida and that dinoflagellate blooms may initiate from seed populations well offshore. Steidinger (1975b) postulated that the offshore seed populations could be either resting pelagic cells or benthic resting cysts (hypnozygotes) from which blooms could initiate and be transported inshore with the aid of physical factors. For instance, Roberts (1979) confirmed that, in 1976, surface concentrations of *G. breve* increased gradually offshore and were then transported inshore due to winds and currents. Initiation in West Florida, therefore, may well be an offshore phenomenon that accelerates when and if transport to depth and toward shore concentrates red tide cells in the photic zones of shallow waters (Seliger *et al.*,1979). That a process similar to West Florida occurs for the initiation of blooms off South Texas is quite possible, particularly given the prevailing onshore winds in the western Gulf of Mexico.

Temperature is another likely significant factor, supported in part by the apparently strong correlation between surface water temperature patterns and major bloom initiation reported by Baldridge (1975), who claimed that simple indicator patterns of water temperatures from mid-January to early April could predict red tide outbreaks twelve months in advance near Tampa Bay, Florida. He stated that such patterns had already shown strong correlation with five major red tides between 1957 and 1974 at Egmont Key, Florida, but had no desire to claim cause-effect dependency nor to diminish the importance of other environmental conditions favoring bloom initiation. His claim of the strong predictive power of certain surface temperature patterns, however, has not been substantiated since 1974 (K. A. Steidinger, pers. comm.). Though Baldridge's predictive model may not be acceptable, a necessary temperature range may still be required for initiation. Rounsefell and Nelson (1966) cite results of studies that examined temperature effects on *G. breve* which, when combined, defined the survival range from 7^{o}-$32^{o}C$, the range of possible growth from <15^{o}-$30^{o}C$ and optimal temperatures from 16^{o}-$28^{o}C$. Steidinger (1983) cites two sources that document the role of temperature changes in *Protogonyaulax tamarensis* excystment. Anderson and Wall (1978), studying the toxic dinoflagellates *Protogonyaulax tamarensis* and *Gonyaulax excavata* isolated from Cape Cod salt ponds, concluded that an increase in temperature was the main external stimulus for excystment and cited other studies on different dinoflagellate species that had reported identical results with temperature increases.

Walker (1982) has confirmed the *potential* for *G. breve* cells to form hypnozygotes as part of their sexual cycle, but hypnozygotes have not been found on the West Florida shelf to date. The Florida program established to look for and map offshore "seed beds" was canceled, and hypnozygotes have not yet been induced to form in culture (K. A. Steidinger, pers. comm.). Haddad and Carder (1979) propose that if seed beds of *G. breve* hypnozygotes exist on the shelf, the cysts themselves may be carried in suspension to depths shallower than 40 meters when the Loop Current intrudes into shelf waters and may encounter conditions conducive to excystment and growth, raising the possibility of inshore initiation as well as the previously substantiated offshore process (Steidinger, 1975b; Roberts, 1979; Seliger *et al.*,1979). Haddad and Carder (1979) cite numerous instances of deep Loop Current and Eastern Gulf Water (EGW) intrusion onto the shelf that coincided with *G. breve* blooms off West Florida and describe a 1977 Florida bloom that occurred simultaneously with EGW upwelling nearshore. They suggest that some conditions favorable for initiation and subsequent blooms of *G. breve* include the decreased temperatures of the Loop Current and EGW combined with the increased light availability and increased nutrients of the nearshore shelf. Finally, Florida blooms need not arise from excystment of hypnozygotes, for Steidinger (1975a) reports the perennial presence of motile forms of unknown ploidy of *G. breve* at less than 1000 cells/liter in the same area of the West Florida shelf as the potential seed beds. Such background concentrations could also be responsible for the initiation of some blooms.

2. Growth

As early as 1958, Collier suggested that *G. breve* may produce an organic substance that indirectly conditions the water for its own growth in addition to making possible use of biologically active organic compounds, vitamin B12, sulfides and organic chelators. Since red tide outbreaks involving *G. breve* on the Florida Gulf coast were correlated with extended periods of heavy rainfall and subsequent organic input to the sea from river discharge, Aldrich (1962) suggested that vitamins, trace metals and chelators from river waters may facilitate photoautotrophy and thus bloom formation (i. e., growth) in *G. breve* and should be studied further. Collier *et al.* (1969) expanded Collier's 1958 study of organic and inorganic chemicals to determine that chelated metals (e. g., EDTA-Fe), sulfide, nitrogen, phosphorus and vitamins can positively influence the growth of *G. breve*. In a review, Steidinger (1975a) defined support for the growth of *G. breve* in terms of favorable levels of nutrients, growth factors, temperature and salinity. From available data, she characterized *G. breve* blooms, however, as gradual increases in motile cells, not sudden increases in cell division rates. Steidinger and Vargo (1988) cite thesis research that determined light-saturated division rates in *G. breve* from 0.1 to 0.5/day, comparable to what is considered a "normal" dinoflagellate division rate of $\leq$ 1.0/day. If a normal doubling rate is the rule, then immense *G. breve* blooms are not explosive episodes of asexual reproduction, but even division rates of 0.5/day can produce in eight days a concentration of 250,000 cells/liter from an initial density of 20,000/liter (Roberts, 1979). Densities on the order of 10^6/liter, however, are best attributed to physical concentrating factors, as discussed below.

3. Maintenance/Transport

Bloom maintenance may be defined as the persistent presence of a bloom at concentrations above background levels. With support from numerous theoretical treatments of the behavior of semi-buoyant particles, a term that also describes dinoflagellates, Collier (1958) explained that, whereas a complex of biological factors apparently prompt a red tide bloom, physical factors such as water mass convergence, wind-driven currents and convection cells cause its mechanical concentration, a statement reiterated by Steidinger and Ingle (1972), Steidinger (1975a), Roberts (1979) and Seliger *et al*. (1979) (who include tidal influences). *G. breve* is known for its inedibility to grazers (Huntley *et al*., 1986), a definite advantage for maintenance. Huntley *et al*. (1986) add that, not only do noxious dinoflagellate species such as *G. breve* gain an interspecific competitive advantage in survival over edible phytoplankton, they also seem far more likely to be able to maintain bloom proportions in spite of zooplankton grazers when other factors are favorable. Several other factors also contribute to the maintenance of high densities of *G. breve*, including migration of the motile cells (Steidinger, 1975a; Steidinger and Vargo, 1988) and allelopathic substances released by *G. breve* that inhibit the growth of other phytoplankton species (Steidinger and Vargo, 1988) and may aid its own growth (Steidinger, 1983).

4. Decline

It is important to note that the same meteorologic and hydrologic forces that concentrate a red tide bloom can disperse it as well (Steidinger, 1983). Steidinger and Vargo (1988) list the many other ways besides advection that may diminish and terminate any algal bloom: benthic filter feeders, cell death, grazing, life cycle changes, nutrient limitation and parasitism. To this list one may add sinking and toxic natural chemicals, the latter due to Collier's (1958) observation that copper levels in some coastal waters of West Florida were clearly toxic to *G. breve*. Astronomical factors may help explain the tendency for blooms to be seasonal. Aldrich (1962) noted that *G. breve* did not grow in the dark in spite of growth-stimulating additives; the decreasing temperatures and photoperiod of the winter months seem to reduce or prevent the persistence or initiation of toxic blooms (note the trend of a winter decline seen in Fig. 1). Yet atypical winter weather patterns have made exceptions to this general trend, and in areas such as South Texas, mild winter weather and longer photoperiods relative to higher latitudes may have little preventive effect.

X. Available data

A. Causative species

1. *Gymnodinium breve*

G. breve was positively identified as the cause of the major red tide blooms of 1955 and 1986 as well as the 1990-91 bloom within the Brownsville Ship Channel. One may reasonably assume that the bloom of 1935 was due to *G. breve* based on reports of respiratory irritation. The cause of the 1974 red tide remains uncertain, though anything other than *G. breve* would be surprising.

2. *Alexandrium monilata*

It seems very likely that the red tides in Offats Bayou in the 1930s-40s and perhaps earlier (Connell and Cross, 1950) were caused by the chain-forming, armored dinoflagellate *A. monilata*, but confirmation of the species in the bayou did not come until 1952 (Howell, 1953). *A. monilata* was identified in the East Lagoon of Galveston Island in the 1960s (Ray and Aldrich, 1967) and was the cause of two blooms offshore of Galveston in 1971 and 1972 (Wardle et al., 1975). Since then, *A. monilata* blooms have only occurred farther south on the Texas coast, with two documented cases in the Viola Turning Basin of the Corpus Christi Inner Harbor in 1972 and 1975 (Jensen and Bowman, 1975). There are yet unsubstantiated reports of similar blooms in the Brownsville ship channel in 1988 (Dr. Terry Allison, pers. comm).

B. Cell concentrations/other biomass estimates

During the 1990-91 *G. breve* bloom in Brownsville, Tony Reisinger, Marine Extension Agent for Cameron County, collected water samples near the surface at one site in the turning basin of the ship channel from 4 December 1990 to 23 February 1991, noting *G. breve* concentrations along with salinity and surface temperature (Figure 2).

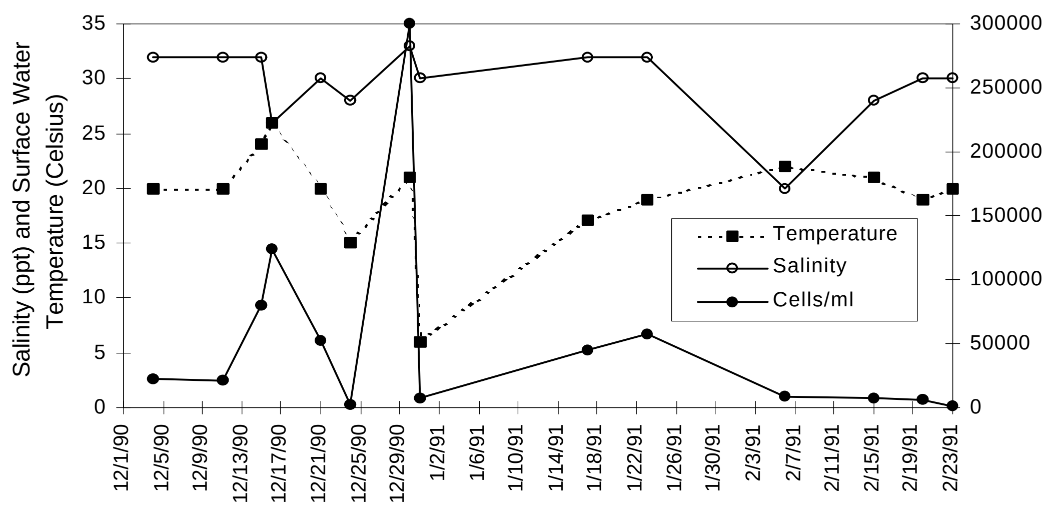

Figure 2. *G. breve* concentrations, salinity and surface temperature over time at one station in the Brownsville Ship Channel Turning Basin (Unpublished data courtesy of T. Reisinger.)

Though the data in Figure 2 appear to reflect some influence by salinity and temperature on cell concentration (determined by hemacytometer), the association is not significant ($p = 0.23$ from multiple regression), a fact not surprising with knowledge of the concentrating effect of winds and currents. For example, the lowest temperature reading in Figure 2, 6°C on 31 December, was due to a strong cold front producing northerly winds, a wind direction quite contrary to the typical southeasterly winds on the South Texas Gulf Coast at that time of year. Northerly winds rather than the temperature decrease most likely reduced cell concentrations in the turning basin, the most distal part of the Brownsville Inner Harbor, from the incredibly high numbers on 30 December which were attributed to the concentrating effects of typical winds and currents (T. Reisinger, pers. comm.). The 1990-91 *G. breve* bloom in Brownsville seems odd relative to the normal offshore initiation and growth of conspecific blooms in West Florida and Texas, as does the small *G. breve* bloom that occurred on 8 January 1987 in Corpus Christi Bay, about two months after the massive 1986 event (Trebatoski, 1988). Viable cells may have remained in the Corpus Christi Bay system to produce that brief but dense bloom, but the 1986 bloom may well have seeded Brownsville's ship channel with hypnozygotes that excysted in response to unknown stimulating factors in the channel prior to the initial fish kill in late November of 1990. This hypothesis could only be confirmed by discovery of cysts in ship channel sediments, if any cysts remain, for the 1990-91 bloom at times occupied much if not all of the ship channel and the associated Lake San Martin, where a sample with 30,000 cells/ml was taken on 13 December 1990 (T. Reisinger, pers. comm.).

The 1986 *G. breve* bloom did penetrate well into the inland waterways of South Texas, passing through such entrances as the ship channel at Port Aransas, where water samples were taken at the pier laboratory of the University of Texas Marine Science Institute (Figure 3; Buskey, unpublished data).

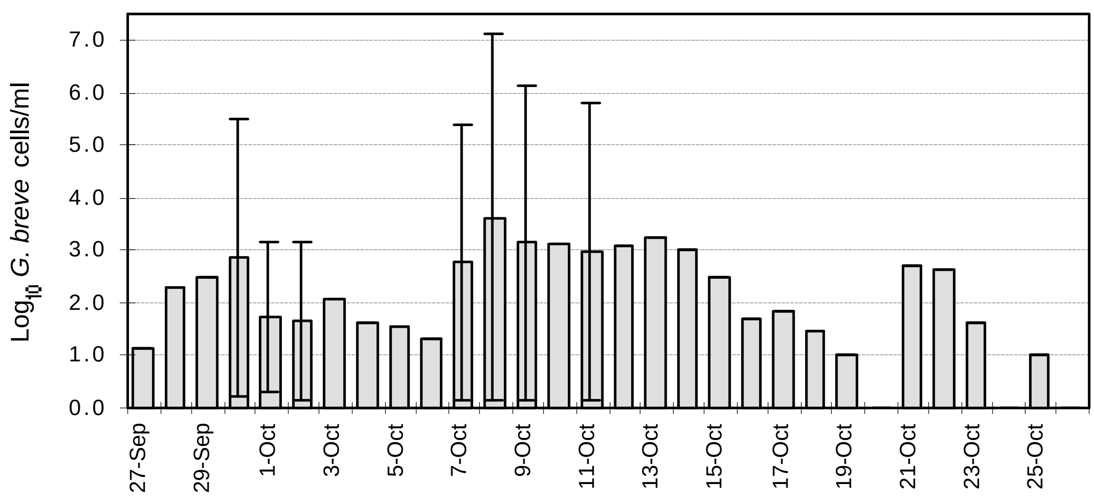

Figure 3. *G. breve* concentrations as means or single counts from water sampled at the UTMSI Pier Lab, Port Aransas in 1986. Error bars are ± $\log_{10}$ standard errors.

C. <u>Spatial and temporal bloom distributions</u>

Only data from the 1986 *G. breve* bloom provide enough information on spatial and temporal distribution of any major bloom. The extent of the 1986 bloom can be depicted in terms of coastal Texas counties with dinoflagellates present in their nearshore waters in concentrations detectable by aerial survey (Table 2).

Table 2. Confirmation of *G. breve* presence by twelve aerial surveys of the nearshore waters and bays of coastal Texas counties from Galveston southward to the Mexican border (excluding Jackson County) in the fall of 1986.* "X" indicates confirmed observation; "?" indicates unconfirmed presence north of Matagorda Bay. (Data from Trebatoski, 1988.)

	SEP 4	SEP 9	SEP 10	SEP 12	SEP 14	SEP 16	SEP 22	SEP 26	SEP 29	OCT 10	OCT 14	OCT 16
Galveston												
Brazoria												
Matagorda	X	?	X	X	X	X	X	X	X	X	X	X
Calhoun	X	X	X	X	X	X	X	X	X	X	X	X
Refugio		X	X		X	X	X	X	X	X	X	X
Aransas		X	X		X	X	X	X	X	X	X	X
San Patricio								X	X	X	X	X
Nueces											X	X
Kleberg											X	X
Kenedy											X	X
Willacy												X
Cameron												X

***Notes:** (1) This *G. breve* red tide was first observed near Galveston Island on 27 August 1986 but was no longer visible to aerial surveys north of the border between Matagorda and Brazoria Counties by 4 September. (2) Aerial surveys on 23 and 24 October 1986 reported no visible red tide along Texas shores.

Of special interest is the fact that no red tide was visible by air only one week after the maximum extent of *G. breve* presence along the Texas coast. Spatial distributions may vary widely, to some degree depending on whether the bloom is inshore or offshore. Temporal distributions are also widely variable and may change by many orders of magnitude in relatively short periods.

D. Fish kills

An estimated 2 million pounds of dead fish resulted from the 1935 red tide, for which the species responsible was likely *G. breve* (Snider, 1987). A widely documented fish kill, again apparently due to *G. breve*, littered the Gulf coast from a point 17 miles north of Port Isabel, Texas to a 120-mile stretch in the Mexican state of Tamaulipas in September of 1955. The 1974 red tide well offshore of Brownsville and Matamoros caused a massive fish kill that eventually littered Mexican beaches, but no estimates of the extent of fish mortality are known. The bulk of available data on fish mortality is associated with the *G. breve* red tide of 1986; Trebatoski (1988) includes an extensive list of all fish species that suffered mortality as identified by the Texas Parks and Wildlife Department. Table 3 summarizes the minimum numbers of individuals killed for seven common fish species of recreational or commercial importance (slightly modified from Texas Parks and Wildlife Department, 1986).

Table 3. Minimum estimates of fish killed by the *G. breve* red tide of 1986 in inshore and offshore Texas waters. (Data from Texas Parks and Wildlife Department, 1986.)

Area	Selected Species							
	Red Drum	Spotted Seatrout	Southern Flounder	Atlantic Croaker	Black Drum	Gulf Menhaden	Striped Mullet	Total
Bays	15,800	41,300	38,200	70,000	2,100	480,000	790,000	1,437,400
Gulf	27,100	39,500	2,800	172,000	1,700	2,770,000	3,240,000	6,253,100
Total	42,900	80,800	41,000	242,000	3,800	3,250,000	4,030,000	7,690,500

E. Shellfish beds

Among many other duties, the Division of Seafood Safety in the Texas Department of Health is responsible for determining acceptable levels of red tide contamination in shellfish meats and closing shellfish beds when meats contain above-threshold levels of toxin. Since 1986, South Texas bays and inshore bodies of water, including two of those in the Corpus Christi Bay National Estuary region, have faced closure for varied lengths of time as indicated in Table 4. Because shellfish are principally harvested in waters north of Port Aransas and those are the sites most frequently sampled by the Texas Department of Health (G. Heideman, pers. comm.), only those bodies of water from Aransas Bay and northward are listed in Table 4. Notice the duration of some closures and the dates of those shellfish beds that were closed well after the 1986 *G. breve* red tide. Continued shellfish contamination after the 1986 bloom and the dates of later incidents of contamination imply that *G. breve* either blooms with a frequency and/or persists to degrees only poorly realized at present (*cf.* Table 1 and associated text in Section II. A.).

Table 4. Dates of closure due to red tide (*G. breve*) contamination and subsequent reopening of selected South Texas shellfish harvesting areas from 1986-1990 by order of the Texas Department of Health. (Data courtesy of G. Heideman, Texas Department of Health.)

Area	Status	1986	1987	1988	1989	1990
East Matagorda Bay	CLOSED	6 Sep				
	REOPENED	4 Dec				
Matagorda Bay	CLOSED	6 Sep				
	REOPENED		2 Dec			
Tres Palacios Bay	CLOSED	6 Sep				
	REOPENED		20 Feb			
Carancahua Bay	CLOSED	6 Sep				
	REOPENED		20 Feb			
Lavaca Bay	CLOSED	6 Sep				
	REOPENED		20 Feb (in part)	13 Feb (all)		
Powderhorn Lake	CLOSED	6 Sep				
	REOPENED			15 Oct		
Espiritu Santo Bay	CLOSED	6 Sep				
	REOPENED			15 Oct		
San Antonio Bay	CLOSED	6 Sep				
	REOPENED	14 Dec				
Mesquite Bay	CLOSED	6 Sep				
	REOPENED		20 Feb			
Copano Bay*	CLOSED	6 Sep				25 Aug
	REOPENED		20 Feb			2 Sep
Aransas Bay*	CLOSED	6 Sep	10 Jan			25 Aug
	REOPENED		1 Jan; 20 Feb			2 Sep

*These bays are included in the Corpus Christi Bay National Estuary region.

F. Gulf of Mexico circulation

Elliot (1982) presented convincing evidence of one or more anti-cyclonic eddies or gyres that form and depart annually from the Gulf Stream's Loop Current west of Florida to migrate westward, maintaining some structural and thermal integrity for as long as a year. Hofmann and Worley (1986) later substantiated the existence of these gyres, and satellite data have shown that the Loop Current occasionally intrudes onto the West Florida Shelf (P. A. Tester, pers. comm.) where *G. breve* blooms typically initiate (Steidinger, 1975b). Already documented is the apparent transport of *G. breve* seed populations from the West Florida Shelf in the Loop Current around the Florida peninsula to the shores of North Carolina via the Gulf Stream, the cause of a novel bloom there in late 1987 (Tester *et al*., 1991).

Should entrainment of seed populations occur in the Loop Current followed by gyre formation, subsequent eddy transport could carry *G. breve* populations to the Gulf Coast of Texas and Mexico. Once in the vicinity of the Texas-Mexico Shelf, surface circulation patterns could work in concert with the decaying anti-cyclonic gyre to integrate gyre waters and their plankton into the westward coastal current described by Barron and Vastano (1994). The westward coastal current results from the inferred existence of a cyclonic gyre normally present from September through May, the southernmost extent of which marks a convergence of coastal currents driven by the prevailing southerly to southeasterly winds in the Western Gulf of Mexico (Cochrane and Kelly, 1986; Hofmann and Worley, 1986). The prevailing winds, countered somewhat in winter by the northerly winds of cold fronts, produce a convergence of coastal flow patterns at a seasonally variable location somewhere between the Matagorda Peninsula and Brownsville (Watson and Behrens, 1970; Barron and Vastano, 1994). The geopotential anomaly data of Cochrane and Kelly (1986), according to Barron and Vastano (1994), can only describe a very general cyclonic current pattern off the Texas-Louisiana Shelf that is subject to significant short-term variability. That variability, however, does not preclude the possibility that both the South Texas coastal flow convergence and the cyclonic gyre on the Texas-Louisiana Shelf could bring *G. breve* populations into nearshore waters as far north as Galveston (the initial site of the 1986 bloom) or along the coast of South Texas and Mexico (as in the offshore blooms of 1935, 1955 and 1974) whether *G. breve* is resident in the offshore waters of the Texas shelf (Geesey and Tester, 1993) or transported by anticyclonic gyre from the Eastern Gulf. The same coastal current patterns (the convergence and cyclonic gyre) could facilitate immigration of *A. monilata* populations from the north central Gulf, as described below.

XI. Potential status of red tide species in Texas coastal waters

Any potential means of controlling *Gymnodinium breve* (and probably *Alexandrium monilata*) blooms that involves the destruction of the cells may do more to exacerbate rather than prevent or diminish the toxic effect of the bloom. For example, a cytolytic chemical extracted from a blue-green alga together with an effective, non-toxic delivery medium could be used to reduce dense concentrations of *G. breve* (Eng-Wilmot *et al.*, 1979a,b) but would prompt the release of brevetoxin upon lysis. The potential status of *G. breve* and *A. monilata* as problematic bloom species along the South Texas Gulf Coast, therefore, may not be subject to human control except via reduction of anthropogenic eutrophication of inshore and coastal waters, if excess nutrients actually promote toxic dinoflagellate blooms (Hallegraeff, 1993).

Regarding the potential status of *A. monilata*, Howell's (1953) work on Florida's east coast predated documentation of *A. monilata* blooms and associated fish kills on the west coast of Florida by almost twenty years (Williams and Ingle, 1972), though the first detection of this dinoflagellate south of Fort Myers, Florida actually occurred in early August of 1966. A fish kill soon followed, and from the first report of mortality on 16 August until the end of that month, high cell counts discolored the waters and continued to kill fish between Tampa Bay and Cape Romano. *A. monilata* concentrations finally fell to low levels by late September. Williams and Ingle (1972) pointed out that records of *A. monilata* up to that time had been known only from estuaries such as those in the Chesapeake Bay, on the coast of Venezuela and in the Galveston, Texas area. They also found high concentrations from less than a mile to 42 miles offshore of West Florida in late 1966, with a maximum of slightly over 1.3 million cells/l at a site 400 meters out from the barrier islands near Sarasota on 21 August. The possibility exists, therefore, for offshore blooms of this dinoflagellate in South Texas as well.

Because *A. monilata* does not contaminate shellfish and may have only a slight impact on finfish depending on the location, small blooms may be frequent in South Texas, escaping offical attention and documentation. Seed populations may be arriving from the north central Gulf of Mexico, also, for *A. monilata* cells from a widespread bloom in September of 1980 off Louisiana not only occupied numerous bayous and sounds but were found in large numbers in water samples from west of the Mississippi River (Perry, 1980), exposing them to possible transport to Texas in the westward coastal current resulting from the river's outflow. Several *A. monilata* blooms occurred at about that time in the north central Gulf, one in August 1979, the one mentioned above and another in July 1981 (Perry and McLelland, 1981). Those outbreaks showed some correlation with lowered salinity which, if causal, may prompt blooms along the Texas coast should a hurricane or tropical storm decrease salinities in inshore and nearshore waters, perhaps especially in areas that have suffered previous *A. monilata* blooms.

Discussion of the postulated trans-Gulf movement of *G. breve* populations in Loop Current gyres, if it occurs, should not obscure the potential for endemic populations of the dinoflagellate in the offshore waters of Texas to seed nearshore blooms. Geesey and Tester (1993) report that *G. breve* is found throughout the Gulf of Mexico, but, until their study, its cell density in nearshore and offshore waters of various depths was largely unknown. For twelve months beginning in March of 1990, NOAA vessels sampled 61 stations throughout the Gulf of Mexico from depths of 0 to >150 m. The density of *G. breve* in shallow, well-mixed waters was constant, but in deeper waters with a thermocline, the dinoflagellate was more abundant near the surface. Concentrations in central Gulf waters remained at <10 cells/ml throughout the year. Coastal stations generally registered the highest densities at ≥100 cells/ml, including two stations offshore of Galveston, Texas. Concentrations from 1-100 cells/ml occurred at coastal stations between St. Joseph Island and Matagorda Island. With the well-documented westward coastal current along the Texas coast (Barron and Vastano, 1994), concentrations of *G. breve* at ≥100 cells/ml could theoretically be found anywhere along the coastline included in the Corpus Christi Bay National Estuary region. The low frequency of major offshore blooms implies that conditions favorable for initiation do not commonly occur in South Texas waters, but the frequent detection of brevetoxin-contaminated shellfish and the closures of shellfish beds by the Texas Department of Health imply that red tide blooms often occur without being otherwise documented (G. Heideman, pers. comm.; see Tables 1 and 4). Similarly, Steidinger's (1975) statement that 75% of *G. breve* blooms that begin offshore of West Florida never make it to nearshore waters may also apply to offshore waters of South

Texas, a possibility that may only be substantiated if toxic dinoflagellates become the focus of an offshore sampling program.

Besides the unknown extent of the negative economic impact of *G. breve* blooms on the South Texas shellfishing industry, not to mention recreational fishing and tourism, the relatively infrequent red tide problems experienced in Texas coastal and inshore waters do not apparently require any changes in current marine policy. Red tide blooms should be understood as naturally occurring events, unless *G. breve* has been or could be introduced by the discharge of ships ballast water containing viable cells or hypnozygotes (Hallegraeff and Bolch, 1992). Should toxic blooms in Texas increase in frequency and severity, however, Texas marine policy should definitely change to provide warning of bloom initiation, expansion and transport and to collect the data necessary to define the factors involved in each step of a bloom.

XII. Identification of data and information gaps

1. The most obvious gap is in the lack of consistent data on red tide concentrations during and after a bloom (if not also before). This requires regular water sampling of established sites that ideally includes measurement of *in situ* temperature, salinity and perhaps winds and currents. Samples should then be analyzed with respect to nutrients and biologically active organic compounds as well as cell concentrations.

2. Thorough sediment analyses, with the object of looking for hypnozygotes at the bottom of such areas as the turning basins in Corpus Christi Inner Harbor and the Brownsville Ship Channel, would provide useful and novel information on the life cycles of both *A. monilata* and *G. breve* in Texas waters regardless of the results. Similar analyses of ship's ballast water for cysts or cells in cargo vessels coming from ports known to have *G. breve* blooms (such as those on Florida's West Coast) would also be useful (Hallegraeff and Bolch, 1992).

3. Examining future offshore *G. breve* blooms with continually available satellite imagery (Gallegos, 1990) and aerial or shipboard means of determining temperature, salinity, nutrients and the bloom's surface coverage would be useful in delineating initiation, growth and eddy transport factors. Likewise, conducting regular sampling of the coastal current and sites of previous *A. monilata* blooms would be helpful but perhaps not as high a priority relative to the greater negative impact of *G. breve* blooms.

4. Automatic notification of incidents of shellfish contamination and information transfer between the Shellfish Sanitation Division of the Texas Department of Health and scientists in both academia and other public agencies who are interested in toxic blooms would greatly facilitate timely work with *G. breve* whenever concentrations are high enough to produce positive toxin bioassays. This notification could be as simple, inexpensive and efficient as one message sent to a standard list of researchers and governmental agencies. In turn, any recipient would also be able to notify the

Department of Health and all other listed recipients of any new blooms. In fact, the bulletin board-style service of the recently established "TexCoast" on the Internet may serve in this capacity. [For further information on "TexCoast," contact Don Hockaday (hockaday@panam.edu) or Dr. Terry Whitledge (terry@utmsi.zo.utexas.edu).]

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XIV. Materials and Methods: Unpublished Data

Ken H. Dutton: Seagrass Density and Biomass.

Measurements of total plant biomass were made at 2 to 3 month intervals from four replicate samples collected at the two stations with a 9 cm diameter coring device. Samples were thoroughly cleaned of any epiphyte material in the laboratory, separated into above-ground and below-ground live biomass (to calculate root:shoot ratios) and dried at 60 ^{o}C to a constant weight. Results are expressed as total biomass (g dry wt m^{-2}) of all shoot, rhizome and root material collected in each core. Measurements of leaf elongation rate and shoot production were collected using the leaf-clipping technique described in Virnstein 1982. for *Halodule wrightii* (the leaves of *H. wrightii* are too thin for leaf-tagging techniques). Shoots were clipped about 2 cm above the basal sheath to permit regrowth, and cores were collected from each clipped area to measure net growth at 3 to 6 week intervals. In the laboratory, the length of the newly formed blades was recorded for individual shoots and all new blade material was pooled from each of four replicate cores for determination of shoot production on a dry weight basis. the mean leaf elongation rate for each replicate core sample was based on the measurement of 20 to 30 blades (Adapted from Dunton 1994).

G. Joan Holt: Larval Feeding and Survival

Studies were carried out in brown tide containing ponds at the GCCA hatchery in Corpus Christi Texas. Feeding studies were carried out in 20 oz soda bottles in which the neck had been removed and 3, 8 cm X 5 cm, panels were cut. The resulting openings were covered with 100 µm nitex mesh nets. For laboratory studies, the bottles were placed inside 1 liter beakers filled with either 48 µm filtered brown tide water (with a concentration of brown tide cells of 1 million ml^{-1} or greater) or control sea water (without brown tide). For field studies, the bottles were placed in either a 48 µm mesh bag, or a control water filled plastic bag and hung from a floating rack. Five to fifteen larvae, all the same age, were placed in each bottle, and allowed to acclimate for 1 hour prior to food addition. The 5 and 7 day old larvae were fed rotifers at a concentration of 5 ml^{-1} . The 14 day old larvae were fed *Artemia* at a concentration of 3 ml^{-1}. After a one hour feeding time the larvae were removed and gut dissection was performed to count the number of prey items consumed.

Hatch rates and survival studies in the field were also carried out with the bagged bottles hung from the floating rack. While the laboratory studies were performed in 100 ml beakers filled with the test treatments of brown tide water or control seawater. To each treatment a defined number of eggs were added. The eggs were left overnight and the unhatched eggs and dead larvae were removed and counted to determine hatching rates and day 1 survival rates. Each day of the experiment the dead larvae were removed and counted to obtain survival rates.

Scott A. Holt: Larval Densities.

Larvae were collected with five replicate ichthyoplankton tows using a 1-m net (500 µm mesh) attached to an epibenthic sled pulled through the lower 1m of the water column. The volume of water filtered for each tow was measured with a mechanical flowmeter. Samples were preserved in 5% formalin or 70% ethanol. All sciaenids in the samples were identified to species (except *Menticirrhus sp.*), enumerated, and measured. Larval densities are expressed an number per 1000 m^3 of water (adapted from Holt, et al. 1994).

Paul A. Montagna: Benthic Biomass, Abundance, and Diversity.

The microfauna were sampled with diver held core tubes with diameters of 6.7 cm. The cores were sectioned at the 0-3 cm and 3-10 cm depth intervals. The meiofauna were sampled with diver held core tubes with diameters of 1.8 cm. These cores were sectioned at the 0-1 cm and 1-3 cm depth intervals. Three replicates, taken within a 2m radius, of each sample was obtained. Samples were preserved with 5% buffered formalin, sorted, identified and counted. The macrofauna samples were used to measure biomass. Samples were dried for 24 hr. at 55^{o}C and weighed. Before drying, mollusks were placed in 1N HCl to dissolve the carbonate shells, and washed (adapted from Montagna and Kalke 1992).

Dean A. Stockwell: Chlorophyll a.

See Chlorophyll a analysis methods from Terry E. Whitledge: Nutrient and Hydrographic Conditions.

Terry E. Whitledge: Nutrient and Hydrographic Conditions.

Samples were collected monthly from 57 stations in upper Laguna Madre and Mansfield Pass in lower Laguna Madre. A SeaBird model SBE 19 CTD profiler was used to obtain salinity and temperature data with respect to depth. Discrete water samples for salinity by refractometer, nutrients (nitrate, ammonium, nitrite, phosphate and silicate), chlorophyll a and Phaeophytin were collected near the surface by hand, and near the bottom with a Van Dorn style water sampler. The samples were collected in clean pre- labeled polyethylene bottles and immediately chilled with ice in the dark. Secchi depths were measured on all stations.

Nutrient analyses were determined on the chilled samples with a segmented flow automated chemical analyzer using methods developed for marine and estuarine waters (Whitledge et al. 1981, 1989) Chlorophyll and phaeopigment measurements were determined by the fluorometric method (Holm-Hansen et al. 1965), with modification for 60% acetone: 40% DMSO extraction at 4 ^{o}C (Dagg and Whitledge, 1991, Stockwell 1989) (adapted from Whitledge 1991).

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XV. Annotated Bibliography

THE ANNOTATED BIBLIOGRAPHY OF THE "BROWN TIDE AND RED TIDE CURRENT STATUS" CONTRACT WITH THE CCBNEP

[All entries pertain wholly or in part to red or brown tide events or experiments; if a source is general, key words will reflect only sections pertinent to brown or red tide.]

Author: Abdelghani, A., Hartley, W. R., Esmundo, F. R., and Harris, T. F.
Date: 1994
Title: *Biological and chemical contaminants in the Gulf of Mexico and the potential impact on public health: a characterization report*
Pages: 77 pp.
Source: Tulane University School of Public Health and Tropical Medicine, New Orleans, LA
Key words: biological contaminant, Gulf of Mexico, public health, biotoxin, red tide, dinoflagellate, bloom, *Gymnodinium breve*, neurotoxin, neurotoxic shellfish poisoning (NSP)
Summary: A small portion of this unpublished draft report describes briefly and in general terms the negative effects of *Gymnodinium breve* red tide on people who ingest contaminated shellfish or inhale the toxin as an aerosol as well as on other members of the marine ecosystem. A list of red tide occurrences in Florida from 1975-1991 follows. No cases of NSP have been reported from any state other than Florida, and while red tides have occurred in Florida and Texas, none have been reported for Alabama, Mississippi or Louisiana.
Methods: N/A (Draft report)
QA/QC: N/A
Contact: Dr. Fred Kopfler
Source Inst.: Not available; contact by phone at (601) 688-2712.

Author: Aldrich, D. V.
Date: 1962
Title: Photoautotrophy in *Gymnodinium breve* Davis
Journal: *Science* 137(3534):988-990
Key words: *Gymnodinium breve*, photoautotrophy, culture, Florida, red tide, dinoflagellate, light, carbon dioxide, growth, micronutrients
Summary: Since red tide outbreaks involving *Gymnodinium breve* on the Florida Gulf coast were correlated with extended periods of heavy rainfall and subsequent organic input to the sea from river discharge, the author tested a multitude of organic substances as potential direct energy sources for *G. breve*. Light and carbon dioxide, however, were the principal growth requirements. No growth occurred in the dark in spite of additives. It is therefore unlikely that heterotrophy plays a large role in bloom formation. Vitamins, trace metals and chelators from river

waters may facilitate photoautotrophy and thus bloom formation in *G. breve* and should be studied further.

Methods: See text (no divisions).
QA/QC: None *per se*; see text.
Contact: David V. Aldrich
Source Inst.: Bureau of Commercial Fisheries, Biological Laboratory, Galveston, Texas, USA

Author: Aldrich, D. V., and Wilson, W. B.
Date: 1960
Title: The effect of salinity on growth of *Gymnodinium breve* Davis
Journal: *Biol. Bull.* 119:57-64
Key words: salinity, growth, *Gymnodinium breve*, dinoflagellate, bloom, red tide, culture
Summary: Bacteria-free cultures of *Gymnodinium breve* experienced media with salinities ranging from 6.3 to 46.0 ppt, growing best between 27 and 37 ppt. Some organisms survived salinities as low as 22.5 and as high as 46.0 ppt for ten weeks; there was no indication of reduced survival at the extremes of 24.8 and 46.0 ppt. The authors conclude that typical Gulf of Mexico salinities should not impose restrictions on the growth of this dinoflagellate, though water with salinities of 24 ppt or less should.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: David V. Aldrich
Source Inst.: Biological Laboratory, U. S. Bureau of Commercial Fisheries, Galveston, Texas, USA

Author: Aldrich, D. V., Ray, S. M., and Wilson, W. B.
Date: 1967
Title: *Gonyaulax monilata*: population growth and development of toxicity in cultures
Journal: *J. Protozool.* 14(4):636-639
Key words: *Gonyaulax monilata*, growth, toxicity, culture, dinoflagellate, *Lebistes reticulatus*, autolysis
Summary: The chain-forming dinoflagellate *Gonyaulax monilata* [now known as *Alexandrium monilata*] was cultured in three 8-liter and four 12-liter containers, the population densities of which were estimated weekly for 17 weeks. Populations peaked at 3-5 weeks, declined from 6-10 weeks and usually stabilized thereafter until the final week. Populations that showed more rapid increase had the greatest proportion of long chains, a possible growth index, and peak toxicity (gauged by the toxic effect on the guppy, *Lebistes reticulatus*) occurred only when cultures had been in decline for a month, indicating autolytic release of toxin, and had no relationship to estimated cell density.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: David V. Aldrich
Source Inst.: Marine Laboratory, Texas A & M University, Galveston, TX 77550 USA

Author: Anderson, D. M.

Date: 1994
Title: Red tides
Journal: *Scientific American*, August 1994
Key words: red tide, bloom, phytoplankton, dinoflagellate, cyst, shellfish poisoning, biotoxin, *Gymnodinium breve*, pollution, ballast water
Summary: The author presents a summary of the deleterious effects of toxic red tide blooms. Topics addressed are biology, including cyst formation and germination; toxin characteristics and poisoning; initiation, growth and hydrologic transport of bloom species; the correlation between blooms and increasing coastal pollution; and novel red tide infestations following transport in the ballast water of ships.
Methods: None (summary)
QA/QC: N/A
Contact: Donald M. Anderson
Source Inst.: Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA

Author: Anderson, D. M., and Wall, D.
Date: 1978
Title: Potential importance of benthic cysts of Gonyaulax tamarensis and G. excavata in initiating toxic dinoflagellate blooms
Journal: *Journal of Phycology* 14(2):224-234
Key words: cyst, *Gonyaulax* [later *Protogonyaulax*] *tamarensis*, *Gonyaulax excavata*, dinoflagellate, bloom, hypnocysts, excystment, temperature, red tide, pellicle cyst
Summary: Sediments from salt ponds in Cape Cod, Massachusetts yielded hypnocysts of two toxic dinoflagellate species that were later successfully germinated by temperature increase alone (to 16°C) after incubation for six months at 5°C, unaffected by nutrient or chelator concentrations nor light regime. The authors conclude that hypnocysts do seed recurrent annual blooms. The hypnocysts are evidently sexual zygotes whereas a form of asexual cyst commonly formed in laboratory cultures, termed a "pellicle cyst," is less durable, cannot overwinter in nature and most likely does not produce toxic blooms. Excystments of hypnocysts with increasing temperature has been demonstrated in several other dinoflagellate species [and could possibly apply to *Gymnodinium breve* and *Alexandrium monilata*].
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Donald Mark Anderson
Source Inst.: Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA

Author: Anderson, D. M., Kulis, D. M. and Cosper, E. M.
Date: 1989
Title/Chap.: Immunofluorescent detection of the brown tide organism, *Aureococcus anophagefferens*
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35

Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 213-228
Publisher: Springer-Verlag
Key words: immunofluorescence, brown tide, *Aureococcus anophagefferens*, bloom, chrysophyte, picoplankton, antibodies, antiserum
Summary: The authors report the rapid, accurate detection of the brown tide organism, *Aureococcus anophagefferens*, with immunofluorescent detection methods, even when the phytoplankton sample is mixed with *A. anophagefferens* in low relative abundance. The antiserum at effective concentrations did not cross-react with any of 46 other phytoplankton cultures from 5 algal classes, including 20 species from the class Chrysophycophyta; at higher antiserum concentrations, cross-reactivity occurred with *Pelagococcus subviridis*, which shares some ultrastructural and possibly phylogenetic similarities. The technique may also reliably serve in detecting the presence of *A. anophagefferens* in variously preserved samples several years old.
Methods: See "Methods"
QA/QC: None *per se*; see "Results"
Contact: Donald M. Anderson
Source Inst.: Biology Department, Woods Hole Oceanographic Institution
Woods Hole, MA 02543 USA

Author: Anderson, D. M., Keafer, B. A., Kulis, D. M., Waters, R. M. and Nuzzi, R.
Date: 1993
Title: An immunofluorescent survey of the brown tide chrysophyte *Aureococcus anophagefferens* along the northeast coast of the United States
Journal: *Journal of Plankton Research* 15(5):563-580
Key words: immunofluorescence, brown tide, chrysophyte, *Aureococcus anophagefferens*
Summary: The authors conducted surveys from Portsmouth, NH to Chesapeake Bay in 1988 and 1990 to determine the population distribution of the brown tide chrysophyte *Aureococcus anophagefferens*. A species-specific immunofluorescent technique sensitive to as few as 10-20 cells/ml revealed that water samples from almost half of the stations to the north and south of the geographic center of the brown tide blooms of 1985 (the Long Island area and Barnegat Bay, NJ, where high concentrations still existed), *A. anophagefferens* was detected at very low cell concentrations within a PSU salinity range of 18-32. Many of these stations, both open coastal and estuarine, have no history of a brown tide bloom, yet apparently have the potential.
Methods: See "Method."
QA/QC: None *per se*; see "Method."
Contact: Donald M. Anderson
Source Inst.: Woods Hole Oceanographic Institution, Biology Department, Woods Hole, MA 02543 USA

Author: Baden, D. G. and Tomas, C. R.
Date: 1989
Title/Chap.: Variations in major toxin composition for six clones of *Ptychodiscus brevis*

Book: *Red tides: biology, environmental science, and toxicology*. Proceedings of the First International Symposium on Red Tides held November 10-14, 1987, in Takamatsu, Kagawa Prefecture, Japan
Editor: T. Okaichi, D. M. Anderson and T. Nemoto
Pages: 415-418
Publisher: Elsevier Science Publishing Company, Inc., New York
Key words: toxin, clone, high pressure liquid chromatography, bloom, Texas, Florida, isolate, haploid, diploid
Summary: Six *Ptychodiscus brevis* [now *Gymnodinium breve*] clones examined for toxin content included one or more isolated from single cells collected during the 1986 Texas bloom, with the remainder from Florida. The oldest clone (from Florida, ca. 1953) was previously characterized as diploid, whereas the more recent isolates were noted as haploid. In the three toxin fractions analyzed with HPLC, there was wide clonal variability; each of the recent clones was significantly different from the oldest. Obviously, the variability in toxin content between *G. breve* populations experiencing different environmental conditions deserves further attention.
Methods: See "Experimental."
QA/QC: None *per se*; see "Experimental."
Contact: Daniel G. Baden
Source Inst.: University of Miami Rosenstiel School of Marine and Atmospheric Science, Division of Biology and Living Resources, Miami, FL 33149 USA

Author: Baldridge, H. D.
Date: 1975
Title/Chap.: Temperature patterns in the long-range prediction of red tide in Florida waters
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 69-79
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: surface temperature, red tide, Florida, bloom, *Gymnodinium breve*, dinoflagellates, toxin, bloom prediction
Summary: A technique for predicting red tide blooms in the local area of the Gulf near Tampa Bay, Florida that depends on the strong empirical relationship between surface water temperature patterns and major bloom initiation is presented as a means of forecasting the likelihood of outbreaks twelve months in advance. Predictions are based on simple indicator patterns of water temperatures from mid-January to early April, and the author claims that such patterns have already shown strong correlation with five major red tides between 1957 and 1974 at Egmont Key, Florida. No claim is made of cause-effect dependency nor does the author wish to diminish the importance of other environmental conditions favoring bloom initiation.
Methods: See "Methods and Results."
QA/QC: None *per se*; see "Methods and Results."
Contact: H. David Baldridge

Source Inst.: Mote Marine Laboratory, Sarasota, Florida, USA

Author: Barron, C. N., Jr. and Vastano, A. C.
Date: 1994
Title: Satellite observations of surface circulation in the northwestern Gulf of Mexico during March and April 1989
Journal: *Continental Shelf Research* 14(6):607-628
Key words: satellite, surface circulation, Gulf of Mexico, drifter, drogue, Texas-Louisiana Shelf, current, convergence, infrared imagery, sea surface temperature
Summary: Six drift buoys drogued to 2.7 m depth in the northwestern Gulf of Mexico provided eight tracks over the Texas-Louisiana Shelf in March and April of 1989. Tracks indicated cross-slope and cross-shelf water movement northward toward Louisiana from the central western Gulf and a westward coastal current from the Mississippi delta region to Galveston, Texas and farther south. Low-energy current patterns occupied the middle of the northwestern portion of the continental shelf, and a nearshore convergence occurred between the Matagorda Peninsula and southern Padre Island. The effects of wind-induced currents over the shelf could be seen over 7^{o} of longitude and 3^{o} of latitude. Infrared satellite imagery illuminated details of the spatial scale of Gulf circulation.
Methods: See "Observations and Methods."
QA/QC: N/A (Physical oceanography)
Contact: Charlie N. Barron, Jr.
Source Inst.: Satellite Ocean Analysis Research, Department of Oceanography, Texas A & M University, College Station, TX 77843 USA

Author: Beltrami, E. J.
Date: 1989
Title/Ch.: Brown tide dynamics as a catastrophe model
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 307-315
Publisher: Springer-Verlag
Key words: brown tide, *Aureococcus anophagefferens*, mathematical modeling, Long Island
Summary: Some interesting results of this model include infrequent outbreaks of brown tide occurring at irregular intervals with varying severity and persisting from two to five years, while low endemic densities of the brown tide organism persist in the intervals. Within the model, blooms are initiated only when high salinity accompanies ambient waters sufficiently rich in nutrients to sustain a bloom population. While the model itself is not predictive, it may explain the basic dynamics of brown tide outbreaks.
Methods: See "The Model"
QA/QC: N/A

Contact: Edward J. Beltrami
Source Inst.: Department of Applied mathematics, State University of New York, Stony Brook, NY 11794-3600 USA

Author: Beltrami, E. and Cosper, E.
Date: 1993
Title/Ch.: Modeling the temporal dynamics of unusual blooms
Book: *Toxic Phytoplankton Blooms in the Sea*, Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton
Editor: T. J. Smayda and Y. Shimizu
Pages: 731-735
Publisher: Elsevier
Key words: modeling, bloom, brown tide, *Aureococcus anophagefferens*, picoplankton, grazing pressure
Summary: Concentrating on the form of bloom behavior characterized by continuous but variable growth in cell numbers, a need for the right suite of conditions to initiate the bloom and persistence even if conditions diminish, the authors identify and incorporate two major sets of factors into their mathmatical model of bloom dynamics. Using field and laboratory data from the brown tide blooms in Long Island and Narragansett Bay to calibrate the model, the external, meterorological factors combined with the internal factors of trophic system dynamics produced results that implicate low grazing pressure as the principal selective advantage to an *A. anophagefferens* bloom and that mimic the fluctuating cell numbers as a product of chaotic population dynamics.
Methods: See "Mathematical Model."
QA/QC: N/A
Contact: Edward Beltrami
Source Inst.: State University of New York, Stony Brook, New York 11794 USA

Author: Bidigare, R. R.
Date: 1989
Title/Ch.: Photosynthetic pigment composition of the brown tide alga: unique chlorophyll and carotenoid derivatives
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 57-75
Publisher: Springer-Verlag
Key words: Ultraplankton, pigments, brown tide, *Aureococcus anophagefferens*, Chrysophyceae, carotenoids, *Pelagococcus subviridis*, chlorophyll c_3,, fucoxanthin, xanthophyll.
Summary: The author discusses the possible use of pigments unique to ultraplanktonic chrysophytes as a means of identification, particularly with regard to *Aureococcus anophagefferens*, a brown tide microalga. Such pigments include xanthophylls, fucoxanthins, carotenoids and chlorophyll *c*.
Methods: See "Methods."

QA/QC: None *per se*; see "Methods."
Contact: Robert R. Bidigare
Source Inst.: Geochemical & Environmental Research Group, Department of Oceanography, Texas A&M University, College Station, TX 77843 USA

Author: Bricelj, V. M., Epp, J. and Malouf, R. E.
Date: 1987
Title: Intraspecific variation in reproductive and somatic growth cycles of bay scallops *Argopecten irradians*
Journal: *Marine Ecology Progress Series* 36:123-137
Key words: reproductive cycle, somatic growth cycle, bay scallop, *Argopecten irradians*, fecundity, adductor muscle, New York, picoplankton, bloom
Summary: This study examined variability in fecundity, reproductive growth cycles and somatic growth cycles in four New York populations of the bay scallop *Argopecten irradians*. The brown tide bloom of 1985 caused starvation and reduced adult muscle weight by 76% relative to 1984. Once the bloom waned in late summer, surviving scallops showed a 3-fold increase in mean muscle weight in September.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: V. M. Bricelj
Source Inst.: Marine Sciences Research Center, State University of New York at Stony Brook, New York 11794 USA

Author: Bricelj, V. M. and Kuenstner, S. H.
Date: 1989
Title/Ch.: Effects of the "brown tide" on the feeding physiology and growth of bay scallops and mussels
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 491-509
Publisher: Springer-Verlag
Key words: brown tide, bay scallop, mussel, bloom, chrysophyte, *Aureococcus anophagefferens*, *Argopecten irradians*, *Mytilus edulis*, bivalves, Long Island
Summary: This study tests the small size, high density and poor digestibility mechanisms in the interaction between *A. anophagefferens* and juveniles of both mussels and bay scallops in feeding trials. Results indicated neither small size, indigestibility nor poor nutritional quality as reasons for harmful effects in bivalves, but rather the chronic toxicity of *A. anophagefferens* induced by direct contact of brown tide cells in high densities with bivalve tissue.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: V. Monica Bricelj

Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794-5000 USA

Author: Bricelj, V. M., Fisher, N. S., Guckert, J. B. and Fu-Lin, E. C.
Date: 1989
Title/Ch.: Lipid composition and nutritional value of the brown tide alga *Aureococcus anophagefferens*
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 85-100
Publisher: Springer-Verlag
Key words: lipids, brown tide, *Aureococcus anophagefferens*, bloom, chrysophyte, fatty acids
Summary: Of the two hypotheses potentially explaining the brown tide's negative impact on bivalves, chronic toxicity or nutritional inadequacy, this study concerns the latter, analyzing the variable lipid content, lipid fractionation and fatty acid composition of *Aureococcus anophagefferens* in culture during exponential growth and stationary phase with respect to possible deficiencies in polyunsaturated fatty acids essential for bivalve growth. Results indicated no comparative deficiency between essential fatty acids in *A. anophagefferens* and other algae known to be nutritious for bivalves, which suggests that the chronic toxicity hypothesis is more likely.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: V. Monica Bricelj
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794-5000 USA

Author: Buskey, E. J.
Date: 1994
Title: *Impact of a persistent "brown tide" algal bloom on the Laguna Madre of South Texas.* Final report to the Texas Higher Education Coordinating Board, Advanced Technology Program.
Pages: 5 pp.
Key words: brown tide, Pelageophycae, Laguna Madre, chrysophyte, *Halodule wrightii*, *Acartia tonsa*, *Streblospio benedicti*, bay anchovy, black drum, spotted sea trout
Summary: This report summarizes the adverse impact of the Texas brown tide's almost five-year persistence on the flora and fauna of the Laguna Madre, including shoalgrass, copepods, microzooplankton, polychaetes and fish larvae.
Methods: N/A
QA/QC: N/A
Contact: Edward J. Buskey
Source Inst.: Marine Science Institute, The University of Texas at Austin, P. O. Box 1267, Port Aransas, TX 78373 USA

Author: Buskey, E. J., and Stockwell, D. A..
Date: 1993

Title/Ch.: Effects of a persistent "brown tide" on zooplankton populations in the Laguna Madre of South Texas
Book: *Toxic Phytoplankton Blooms in the Sea*
Editor: T. J. Smayda and Y. Shimizu
Pages: 659-666
Publisher: Elsevier Science Publishers B. V
Key words: brown tide, zooplankton, Laguna Madre, Texas, nanoplankton, chrysophyte, mesozooplankton, microzooplankton, Baffin Bay, *Acartia tonsa*
Summary: Relates effects on zooplankton of a brown tide due to an unidentified Type III nanoplanktonic chrysophyte of 4-5 µm diameter that appeared in regions of the South Texas coast centering around the Laguna Madre including Baffin Bay from 6/90-7/91 and continuing. Cell densities ranged from 0.5-6.0 x 10^6 cells/ml, dausing sharp decline in micro- and mesozooplankton populations.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Edward J. Buskey
Source Inst.: Marine Science Institute, The University of Texas at Austin, Port Aransas, TX 78373 USA

Author: Caron, D. A., Lim, E. L., Kunze, H., Cosper, E. M. and Anderson, D. M.
Date: 1989
Title/Ch.: Trophic interactions between nano- and microzooplankton and the "brown tide"
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms* , Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 265-294
Publisher: Springer-Verlag
Key words: nanoplankton, microzooplankton, brown tide, bloom, grazing, *Aureococcus anophagefferens*, chrysophyte, protozoa, Long Island
Summary: Examines the ability of five protozoan species to consume *A. anophagefferens* in laboratory culture, since the size of the brown tide organism is ideal for protozoan grazers. Paradoxically, brown tide outbreaks have suffered no apparent reduction by protozoan grazers that typically reproduce at greater rates than those reported for *A. anophagefferens*. Results revealed that two of the five protozoan grazers were able to consume and outgrow the *A. anophagefferens* cultures. The authors speculate that brown tide organisms could achieve bloom proportions if low densities of protozoan consumers were present at the time of bloom initiation and that this scenario is more likely than chemical inhibition based on the results of these experiments.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: David A. Caron
Source Inst.: Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA
Author: Castro, L. R. and Cowen, R. K.
Date: 1989

Title/Ch.: Growth rates of bay anchovy (*Anchoa mitchilli*) in Great South Bay under recurrent brown tide conditions, summers 1987 and 1988
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms* , Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 663-674
Publisher: Springer-Verlag
Key words: bay anchovy, *Anchoa mitchilli*, Great South Bay, brown tide, larvae, phytoplankton, bloom, growth rate, otolith
Summary: Examining the possible effects of dense brown tide on larval growth rates of bay anchovy ($\leq$ 13 mm SL) in Great South Bay, Long Island, the authors discovered that neither increased turbidity nor elevated average bay surface temperature produced a significant change in average larval growth rates as determined by otolith diameter, though the rates were not corrected for shrinkage and were possibly higher than those reported.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Leonardo R. Castro
Source Inst.: Marine Sciences Research Center, State University of New York at Stony Brook, Stony Brook, NY 11794-5000 USA

Author: Cochrane, J. D., and Kelly, F. J.
Date: 1986
Title: Low-frequency circulation on the Texas-Louisiana continental shelf
Journal: *Journal of Geophysical Research* 91(C9):10,645-10,659
Key words: low-frequency circulation, continental shelf, Texas, Louisiana, coastal current, wind stress, convergence, salinity, geopotential, cyclonic gyre
Summary: The authors, using several data series on coastal winds, current measurements, and distributions of surface salinity and geopotential, offer a sketch of the low-frequency surface circulation above the Texas-Louisiana Shelf. They infer the existence of a cyclonic gyre composed of a nearshore southward coastal jet, an offshore northerly to easterly flow over the shelf break and lateral components completing the circuit. The gyre's southern end marks a convergence of coastal currents between Port Isabel and Port Aransas. The integrity of the gyre was maintained in all months but July.
Methods: None (Data interpretation)
QA/QC: N/A
Contact: J. D. Cochrane
Source Inst.: Department of Oceanography, Texas A & M University, College Station, TX, USA

Author: Collier, A.
Date: 1958
Title: Some biochemical aspects of red tides and related oceanographic problems
Journal: *Limnol. Oceanogr.* 3:33-39

Key words: red tide, bloom, plankton, *Prorocentrum*, *Gymnodinium breve*, Florida, Gulf of Mexico, copper, hydrogen sulfide, dinoflagellate

Summary: The author suggests that a complex of biological factors causes a red tide bloom, and physical factors cause its mechnical concentration. Biologically active organic compounds are important, and the paper discusses their possible modes of action. The armored dinoflagellate *Prorocentrum* served as a means of estimating dinoflagellate potential in terms of producing free organic substances in the aquatic environment. Regarding *G. breve*, the interactions of a particular bacterial colony type and its production of vitamin B12 with the red tide organism implies that the dinoflagellate may be producing an organic substrate that indirectly conditions the water for its own growth. West Florida waters from different sources and collection times have varied effects on *G. breve* growth; this paper describes sulfides as suitable substitutes for organic chelators (and abundantly supplied from West Florida estuaries) and copper as highly toxic to the dinoflagellate (in widely varying concentrations off West Florida).

Methods: None *per se*; see text.

QA/QC: None *per se*.

Contact: Albert Collier

Source Inst.: U. S. Fish and Wildlife Service, Galveston, TX, USA

Author: Collier, A., Wilson, W. B. and Borkowski, M.

Date: 1969

Title: Responses of *Gymnodinium breve* Davis to natural waters of diverse origins

Journal: *J. Phycol*. 5:168-172

Key words: *Gymnodinium breve*, growth, enrichment, chelator, nutrient, Florida, dinoflagellate, sulfide, plankton, bloom

Summary: Using river water and seawater collected from different locations in different seasons on and off the coast of West Florida, the authors examined subsequent growth of the dinoflagellate *Gymnodinium breve* when cultured in those waters with and without enrichment with chelated metals (e. g., EDTA-Fe), sulfide, nitrogen, phosphorus and vitamins. All additions produced enhanced growth relative to controls in river water. For both water types, a large growth response was noted with waters collected during the summer of 1966, perhaps linked to riverine contributions to the seawater samples. Of all additives, sulfides, natural chelators, nitrogen and phosphorus may best contribute to blooms. Given the unpredictability of red tide blooms, the necessity of continual water sampling is implied in order to characterize water quality during a bloom.

Methods: See "Materials and Methods."

QA/QC: None *per se*; see "Materials and Methods."

Contact: Albert Collier

Source Inst.: Department of Biological Science, Florida State University, Tallahassee, FL 32306 USA

Author: Connell, C. H. and Cross, J. B.

Date: 1950

Title: Mass mortality of fish associated with the protozoan *Gonyaulax* in the Gulf of Mexico
Journal: *Science* 112(2909):359-363
Key words: fish, mortality, *Gonyaulax* sp., Gulf of Mexico, Galveston, Texas, *Gonyaulax catenella*
Summary: This paper discusses the correlation of mass mortality of fish with historic reports and a 1949 episode of red tide or luminescent water in a saltwater lagoon near Galveston, Texas. In terms of (1) insufficient cells to define the sutures of the cellulose plates, (2) longer chains of cells and (3) different vectors for the toxin, the 1949 red tide dinoflagellate near Galveston was similar but not identical to *Gonyaulax catenella*, the organism responsible for tainted shellfish and resulting human and mammal mortality (but not fish) on the Pacific coast of North America. Small quantities of sewage pollution, wide and variable readings of dissolved oxygen content and unusually high values for biochemical oxygen demand in the affected lagoon were concurrent with the occurrence of this *Gonyaulax* sp.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Cecil H. Connnell
Source Inst.: Dept. of Preventive Medicine, Medical Branch, Univ. of Texas, Galveston

Author: Cosper, E. M.
Date: 1987
Title: Culturing the "brown tide" alga
Journal: *Applied Phycology Forum*
Key words: culture, brown tide, algae, bloom, Long Island, phytoplankton, Chrysophyceae, *Aureococcus anophagefferens*, growth rate, growth factors
Summary: Attempts to culture the chrysophyte responsible for the algal blooms that devastated eelgrass and bay scallop populations in Long Island bays in 1985 were successful. Isolates exhibited fast growth rates (up to 3/day at 20 degrees C), though growth was poor in f/2-enriched standard media. Natural filtered seawater, however, when combined with f/2 media, produced maximal growth rates, suggesting certain growth factors in the bloom water. The organic additive, sodium glycerophosphate, enhanced growth significantly, whereas other glucose and succinate did not.
Methods: None *per se*; see text (Research note)
QA/QC: N/A
Contact: Elizabeth M. Cosper
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, New York 11794 USA

Author: Cosper, E. M., Dennison, W. C., Carpenter, E. J., Bricelj, V. M., Mitchell, J. G., Duenstner, S. H., Colflesh, D. and Dewey, M.
Date: 1987
Title: Recurrent and persistent brown tide blooms perturb coastal marine ecosystem
Journal: *Estuaries* 10(4):284-290

Key words: brown tide, bloom, chrysophyte, Long Island, eelgrass, bay scallop, Rhode Island, New jersey, microalgae

Summary: Culture experiments with the previously undescribed brown tide microalga implicated a role for stimulatory growth factors in bloom seawater, aided by meterological factors that prompted blooms in Long Island, Rhode Island and New Jersey waters in the summers of 1985 and 1986. Bloom concentrations exceeded 10^9 cells/liter in Long Island bays, harming eelgrass beds and bay scallop populations.

Methods: See "Methods and Materials."

QA/QC: None *per se*; see "Methods and Materials."

Contact: Elizabeth M. Cosper

Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, New York 11794 USA

Author: Cosper, E. M., Carpenter, E. J. and Cottrell, M.

Date: 1989

Title/Ch.: Primary productivity and growth dynamics of the "brown tide" in Long Island embayments

Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35

Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter

Pages: 139-158

Publisher: Springer-Verlag

Key words: brown tide, Long Island, bloom, *Aureococcus anophagefferens*, *Nannochloris* sp., picoplankton, *Pelagococcus subviridis*

Summary: Throughout the brown tide blooms of 1985-88, phytoplankton biomass and productivity did not differ from pre-bloom years, but *Aureococcus anophagefferens* dominated the species composition, apparently controlled by microflagellate grazers, yet still often as dense as 10^8cells/l. No notable changes in inorganic nutrient levels could explain the blooms, though certain organic nutrients such as glycerophosphates and chelators were implicated. Historical blooms in the summers of "small forms" and of usually diverse composition have not been uncommon in Long Island waters. *A. anophagefferens* has been detected in non-bloom densities in northeast coastal waters in general, implying that the Long Island blooms occurred due to unique and persistently favorable conditions for *A. anophagefferens*, conditions which may have stimulated excystation of a possible resting stage.

Methods: See "Methods."

QA/QC: None *per se*; see "Methods."

Contact: Elizabeth M. Cosper

Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Cosper, E. M., Lee, C. and Carpenter, E. J.

Date: 1990

Title/Ch.: Novel "brown tide" blooms in Long Island embayments: a search for the causes

Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 17-28
Publisher: Elsevier
Key words: brown tide, bloom, Long Island, chrysophyte, *Aureococcus anophagefferens*, *Pelagococcus subviridis*, trace elements, chelators, organic nutrients
Summary: Once a suite of favorable environmental factors initiates a bloom, *Aureococcus anophagefferens* appears to have a competitive advantage over other possibly coincident phytoplankton species due to its heterotrophic and photoadaptive capabilities. Factors contributing to blooms may include high salinities resulting from drought, rainfall-induced input of organic and/or micronutrients, reduced grazing pressure and restricted flushing of bay waters. *A. anophagefferens* bears some resemblance to the open ocean chrysophyte, *Pelagococcus subviridis*.
Methods: N/A (review article)
QA/QC: N/A
Contact: Elizabeth M. Cosper
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, New York 11794 USA

Author: Cosper, E. M., Dennison, W., Milligan, A., Carpenter, E. J., Lee, C., Holzapfel, J. and Milanese, L.
Date: 1989
Title/Ch.: An examination of the environmental factors important to initiating and sustaining "brown tide" blooms
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 317-340
Publisher: Springer-Verlag
Key words: brown tide, bloom, Long Island, flushing rate, *Aureococcus anophagefferens*, picoplankton
Summary: The authors hypothesize that the brown tide organism, *Aureococcus anophagefferens*, will likely bloom when long-term anthropogenic and/or other sources of eutrophication combine with atypical meteorological and hydrographical conditions (e.g., high salinity). The competitive superiority of *A. anophagefferens* relative to other phytoplankton does not appear to be the result of an allelopathic (toxic) exudate, but is more likely due to miconutrient needs, efficient use of low light levels, and heterotrophic capabilities, including an unusual ability to take up glutamic acid and glucose rapidly as energy and carbon sources, with a possible reduction in grazing pressure.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Elizabeth M. Cosper
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Cosper, E. M., Garry, R. T., Milligan, A. J. and Doall, M. H.
Date: 1993
Title/Ch.: Iron, selenium and citric acid are critical to the growth of the "brown tide" microalga, *Aureococcus anophagefferens*
Book: *Toxic Phytoplankton Blooms in the Sea*, Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton
Editor: T. J. Smayda and Y. Shimizu
Pages: 667-673
Publisher: Elsevier
Key words: iron, selenium, citric acid, brown tide, microalgae, *Aureococcus anophagefferens*, chelators, trace elements, chrysophyte, bloom
Summary: This study evaluated the impact of chelators and essential trace elements on the growth of *A. anophagefferens*, of which both iron and selenium were found to be critical. Citric acid was the most effective chelator for growth enhancement, and, since it has replaced phosphates in some commercial detergents in New York, the authors suggest that its role in eutrophication should be examined. Using bloom and non-bloom water samples filtered through 5 µm mesh and manipulated with regard to light and Se and/or Fe additions, results indicated that Fe alone increased by several times the growth rates of *A. anophagefferens* in bloom water under high light; only Fe with Se increased *A. anophagefferens* growth rates in non-bloom water, but only at low light levels.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods" and "Results."
Contact: Elizabeth M. Cosper
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Davis, C. C.
Date: 1948
Title: *Gymnodinium brevis* sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico
Journal: *Botanical Gazette* 109(3):358-360
Key words: *Gymnodinium brevis*, discolored water, fish mortality, Gulf of Mexico, Florida, plankton, cell, chromatophores
Summary: The description and classification of the then-novel red tide dinoflagellate now known as *Gymnodinium breve* occupies the majority of text but is preceded by some examples of mass mortality caused by this organism off the west coast of Florida in 1947.
Methods: None (taxonomic description/classification)
QA/QC: N/A
Contact: Charles C. Davis
Source Inst.: University of Miami Marine Laboratory, Coral Gables, Florida, USA

Author: Dennison, W. C., Marshall, G. J. and Wigand, C.
Date: 1989
Title/Ch.: Effect of "brown tide" shading on eelgrass (*Zostera marina* L.) distributions

Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 675-692
Publisher: Springer-Verlag
Key words: brown tide, eelgrass, *Zostera marina*, *Aureococcus anophagefferens*, Long Island, distribution, die-back
Summary: A lack of historical data on eelgrass distributions in Long Island bays prevented the authors from making definitive statements about any deleterious effects by brown tide on eelgrass populations since the summer blooms of 1985-88, yet the brown tide did reduce light available to the eelgrass beds in bloom areas. Most bays had less eelgrass during the 1988 survey than indicated in historic, pre-bloom aerial photographs.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: William C. Dennison
Source Inst.: Horn Point Environmental Laboratories, Center for Environmental and Estuarine Studies, University of Maryland, P. O. Box 775, Cambridge, MD 21613 USA

Author: Deyoe, H. R. and Suttle, C. A.
Date: 1994
Title: The inability of the Texas "brown tide" alga to use nitrate and the role of nitrogen in the initiation of a persistent bloom of this organism.
Journal: *J. Phycol.* 30:800-806
Key words: Texas, brown tide, bloom, nitrate, nitrate reductase, nitrogen, plankton, *Aureococcus anophagefferens*, Laguna Madre, nitrite, ammonium
Summary: The Texas brown tide organism differs slightly but significantly from the New England brown tide alga, *Aureococcus anophagefferens*, in that the Texas brown tide alga apparently lacks the enzyme nitrate reductase, making it unable to use NO_3^- for growth. It can, however, use nitrite and ammonium, the latter of which was in unusually high concentrations after two severe freezes in December 1989 and January 1990 caused declines in invertebrate biomass and mortality in fish populations and apparently stimulated the Texas brown tide bloom.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Hudson R. Deyoe
Source Inst.: CCBNEP, Texas A & M University-Corpus Christi, 6300 Ocean Drive, Corpus Christi, TX 78412 USA

Author: Draper, C., Gainey, L., Shumway, S. and Shapiro, L.
Date: 1990
Title/Ch.: Effects of *Aureococcus anophagefferens* ("brown tide") on the lateral cilia of 5 species of bivalve molluscs
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson

Pages: 128-131
Publisher: Elsevier
Key words: *Aureococcus anophagefferens*, brown tide, cilia, bivalve, mollusc, *Mya arenaria*, *Geukensia demissa*, *Argopecten irradians*, *Mercenaria mercenaria*, *Mytilus edulis*, dopamine
Summary: *Aureococcus anophagefferens* caused significant decreases in lateral ciliary activity in isolated gills of *Mercenaria mercenaria* and *Mytilus edulis* as did the neurotransmitter dopamine. Neither *A. anophagefferens* nor dopamine, however, had any effect on lateral ciliary activity of *Mya arenaria*, *Geukensia demissa* or *Argopecten irradians*.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Christy Draper
Source Inst.: Department of Biological Sciences, University of Southern Maine, Portland, ME 04103 USA

Author: Duguay, L. E., Monteleone, D. M. and Quaglietta, C.-E.
Date: 1989
Title/Ch.: Abundance and distribution of zooplankton and ichthyoplankton in Great South Bay, New York during the brown tide outbreaks of 1985 and 1986
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 599-623
Publisher: Springer-Verlag
Key words: zooplankton, ichthyoplankton, Great South Bay, New York, brown tide, chrysophyte, *Aureococcus anophagefferens*, bivalve larvae, trophodynamics, *Acartia* sp.
Summary: Investigations of plankton trophodynamics in Great South Bay, NY were underway when brown tide blooms of *Aureococcus anophagefferens* occurred in the summers of 1985 and 1986, the former apparently more severe. Summer bivalve larvae were significantly higher in both peak and average density in 1986 as opposed to 1985, confirming previous reports of mortality and/or reduction in tissue dry weights in bivalves exposed to brown tide blooms. The authors speculate that excess rainfall in May and June of 1985 initiated the brown tide, with the bloom occurring at a time when phytoplankton grazers were not abundant.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Linda E. Duguay
Source Inst.: University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, P. O. Box 38, Solomons, MD 20688-0038 USA

Author: Durbin, A. G. and Durbin, E. G.
Date: 1989

Title/Ch.: Effect of the "brown tide" on feeding, size and egg laying rate of adult female *Acartica tonsa*
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 625-646
Publisher: Springer-Verlag
Key words: brown tide, *Acartia tonsa*, picoplankton, Narragansett Bay, chrysophyte, *Aureococcus anophagefferens*, bloom, copepods, Greenwich Bay, protozooplankton
Summary: Relates the impact of a picoalgal bloom in Narragansett Bay beginning in the early summer of 1985. The then undescribed 2 µm chrysophyte, now known as *Aureococcus anophagefferens*, negatively affected egg laying rate, gut pigments, body size and condition factor of adult female *Acartia tonsa* copepods when comparisons were made between field observations and laboratory manipulations. The authors suggest that (1) a regional climatological or hydrographic change affected or worked in concert with temperature, light and nutrients to favor the bloom, and/or (2) predation pressure affected the size composition of the phytoplankton community, favoring the picoplankton that are thought to be controlled by protozooplankton predators.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Ann G. Durbin
Source Inst.: University of Rhode Island, Graduate School of Oceanography, Narragansett, Rhode Island 02882 USA

Author: Dunton, K. H.
Date: 1994
Title: Seasonal growth and biomass of the subtropical seagrass *Halodule wrightii* in relation to continuous measurements of underwater irradiance
Journal: *Marine Biology*
Key words: growth, biomass, seagrass, *Halodule wrightii*, underwater irradiance, PAR, Texas, chrysophyte, brown tide, bloom
Summary: Three different Texas estuaries, including brown tide-stricken Laguna Madre, were sites for studies of continuous underwater irradiance measurements and concurrent leaf elongation and plant biomass for the seagrass *Halodule wrightii* over one to four years. The brown tide bloom significantly decreased spring leaf elongation rates and reduced below-ground biomass by almost 50%.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Ken H. Dunton
Source Inst.: The University of Texas at Austin, Marine Science Institute, P. O. Box 1267, Port Aransas, TX 78373 USA

Author: Dzurica, S.
Date: 1988

Thesis: Role of environmental variables, specifically organic compounds and micronutrients, in the growth of *Aureococcus anophagefferens*
Pages: 122 pp.
Source: Marine Environmental Sciences Program, State University of New York at Stony Brook
Key words: micronutrient, *Aureococcus anophagefferens*, brown tide, microalga, Long Island, chrysophyte, organic phosphorus, chelator, trace metal, uptake rate
Summary: Noting that standard culture media (f/2 Enriched Instant Ocean) supported slow growth rates in Long Island brown tide cultures, the author conducted a series of experiments in an attempt to determine factors contributing to bloom conditions. Organic rather than inorganic phosphorus compounds greatly enhanced growth as did adding the chelators nitrilotriacetic acid and citric acid. Comparisons of uptake rates for C-14 labeled organic compounds between *Aureococcus anophagefferens* and five other species of microalgae which co-occur with the brown tide. *A. anophagefferens* exhibited a faster uptake rate for glutamic acid when accompanied by inorganic nitrogen, but not when glutamic acid was the sole N source. *A. anophagefferens* showed the highest uptake rate of glucose per unit cell volume but not with the highest uptake rate constant per cell. For every compound tested, however, *A. anophagefferens* demonstrated an advantage in uptake rate per unit cell volume.
Methods: See "Methods and Materials," pp. 6-16.
QA/QC: See "Methods and Materials."
Contact: Cindy Lee
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Dzurica, S., Lee, C. and Cosper E. M.
Date: 1989
Title/Ch.: Role of environmental variables, specifically organic compounds and micronutrients, in the growth of the chrysophyte *Aureococcus anophagefferens*
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 229-252
Publisher: Springer-Verlag
Key words: micronutrients, chrysophyte, *Aureococcus anophagefferens*, phytoplankton, bloom, brown tide, organic phosphorus, trace metals, chelators
Summary: With a two-fold purpose, this study sought to tailor culture media to support optimal growth of *Aureococcus anophagefferens* in order to identify possible common environmental factors between culture media and bloom water and to experimentally evaluate growth of *A. anophagefferens* relative to other phytoplankton in an attempt to explain long-term dominance. Replacing inorganic phosphate in f/2 EIO medium with the organic phosphorus compounds glycerophosphate and fructose-1,6-diphosphate stimulated growth in *A. anophagefferens*, as did the chelators citric acid and nitrilotriacetic acid. Trace elements accompanied by the chelator EDTA also enhanced growth. *In situ*

chelation, therefore, may be an important growth factor. *A. anophagefferens* has a more rapid uptake rate for glutamic acid and glucose than three co-occurring phytoplankton species (diatoms and a green alga), perhaps conferring a competitive advantage.

Methods: See "Methods."

QA/QC: None *per se*; see "Methods."

Contact: Susan Dzurica

Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Elliott, B. A.

Date: 1982

Title: Anticyclonic rings in the Gulf of Mexico

Journal: *Journal of Physical Oceanography* 12:1292-1309

Key words: anticyclonic ring, Gulf of Mexico, Loop Current, heat budget, salt budget, Caribbean subtropical underwater, western anticyclonic cell, circulation

Summary: Historical data sets provided evidence that three anticyclonic rings separated from the Loop Current in the eastern Gulf of Mexico during the twelve months following October of 1966. Translating westward at a mean speed of 2.1 km/day, the rings' mean radius was 183 km, and their estimated life span was one year. The heat and salt provided by these rings to the western Gulf must play important roles in the heat and salt budgets of the Gulf. Convective mixing in winter gradually reduced the higher ring salinity to values typical of Gulf of Mexico common water.

Methods: None (Data interpretation)

QA/QC: N/A

Contact: W. D. Nowlin, Jr.

Source Inst.: Department of Oceanography, Texas A & M University, College Station, TX 77843 USA

Author: Eng-Wilmot, D. L., McCoy, L. F., Jr. and Martin, D. F.

Date: 1979

Title/Ch.: Isolation and synergism of a red tide (*Gymnodinium breve*) cytolytic factor(s) from cultures of *Gomphosphaeria aponina*

Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978

Editor: D. L. Taylor and H. H. Seliger

Pages: 355-360

Publisher: Elsevier/North-Holland, Inc.

Key words: red tide, *Gymnodinium breve*, cytolytic factor, *Gomphosphaeria aponina*, dinoflagellate, blue-green alga, aponin

Summary: The blue-green alga *Gomphosphaeria aponina* yields a cytolytic factor ("aponin") active towards the unarmored red tide dinoflagellate *Gymnodinium breve*. Chloroform extractions at neutral pH produced maximum yields of aponin, purified by any one of three chromatographic techniques. Separate fractions showed obvious losses of total and specific activity, and a synergistic relationship among the separate components is supported by evidence.

Methods: See "Materials and Methods."
QA/QC: See "Materials and Methods."
Contact: D. F. Martin
Source Inst.: Department of Chemistry, University of South Florida, Tampa, FL 33620 USA

Author: Eng-Wilmot, D. L., Henningsen, B. F., Martin, D. F. and Moon, R. E.
Date: 1979
Title/Ch.: Model solvent systems for delivery of compounds cytolytic towards *Gymnodinium breve*
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 361-366
Publisher: Elsevier/North-Holland, Inc.
Key words: solvent, cytolytic compounds, *Gymnodinium breve*, aponin, dinoflagellate, sterol, *Gomphosphaeria aponina*, liposomes, micelles, red tide
Summary: A sterol ($C_{29}H_{49}OR$) isolated and purified from cultures of the cyanobacterium *Gomphosphaera aponina* is cytolytic towards the toxigenic red tide dinoflagellate *Gymnodinium breve*. Because the sterol is hydrophobic, it must be delivered to seawater in a non-toxic solvent system. Two are presented as promising for treatment of localized red tide blooms, liposomes and micelles, the latter being superior.
Methods: See "Materials and Methods."
QA/QC: See "Materials and Methods."
Contact: D. L. Eng-Wilmot
Source Inst.: Department of Chemistry, University of Oklahoma, Norman, Oklahoma 73019 USA

Author: Freeberg, L. R., Marshall, A. and Heyl, M.
Date: 1979
Title/Ch.: Interrelationships of *Gymnodinium breve* (Florida red tide) within the phytoplankton community
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 139-144
Publisher: Elsevier/North-Holland, Inc.
Key words: *Gymnodinium breve*, red tide, Florida, phytoplankton, diatom, flagellate, dinoflagellate, lysis, growth, inhibition
Summary: Medium in which *G. breve* had been grown was subsequently used as a medium for each of 28 phytoplankton species in axenic cultures. The medium significantly inhibited growth in 18 species, though its effect, while species-specific, varied within species. The population levels of several diatoms and dinoflagellates and one flagellate barely increased above inoculum concentrations; two dinoflagellate inocula suffered lysis. Toxin extracts totally arrested growth in eight of twelve

species (4 diatoms and 4 dinoflagellates). Column chromotography could not separate the algal inhibition component from the ichthyotoxin.

Methods: See "Materials and Methods."

QA/QC: None *per se*; see "Materials and Methods."

Contact: Larry R. Freeberg

Source Inst.: Mote Marine Laboratory, 1600 City Island Park, Sarasota, Florida

Author: Gaffney, R. J.

Date: 1992

Title: *Brown tide comprehensive assessment and management program summary*

Pages: 40 pp.

Publisher: Suffolk County Department of Health Services, NY

Key words: brown tide, algal bloom, *Aureococcus anophagefferens*, Peconic Bay, Flanders Bay, Shinnecock Bay, Moriches Bay, Great South Bay

Summary: This report concludes that the *Aureococcus anophagefferens* brown tide apparently was not triggered by the conventional macronutrients nitrogen and phosphorus, but may have been caused by other factors such as meteorological patterns and specific chemicals (chelators, organic nutrients, metals). The report recommends, among other things, further research on viral control of the brown tide and the relationship between dimethyl sulfide and zooplankton grazers.

Methods: N/A (Summary report)

QA/QC: N/A

Contact: Robert J. Gaffney, Suffolk County Executive

Source Inst.: Suffolk County Department of Health Services, NY

Author: Gainey, L. F., Jr. and Shumway, S. E.

Date: 1991

Title: The physiological effect of *Aureococcus anophagefferens* ("brown tide") on the lateral cilia of bivalve mollusks

Journal: *Biol. Bull.* 181:298-306

Key words: *Aureococcus anophagefferens*, brown tide, gill cilia, bivalve, mollusk, dopamine, ergometrine

Summary: The isolated gills of eight bivalve mollusks were exposed to *Aureococcus anophagefferens*, the brown tide alga, resulting in a significant decrease in the activity of the lateral cilia of the gills of five of the bivalves, whereas those of three other species were unaffected. Only the presence of the brown tide cells produced such results, and the inhibition was similar to that induced by dopamine. Treatment with the dopamine antagonist ergometrine prevented loss of ciliary activity due to both dopamine and a water-soluble compound derived from brown tide cells exposed to amylase. This dopamine-like, brown tide inhibitory compound was likely released upon partial digestion by the isolated gills.

Methods: See "Materials and Methods."

QA/QC: None *per se*; see "Materials and Methods."

Contact: Louis F. Gainey

Source Inst.: Department of Biological Sciences, University of Southern Maine, Portland, Maine 04103 USA

Author: Gallager, S. M., Stoecker, D. K. and Bricelj, V. M.
Date: 1989
Title/Ch.: Effects of the brown tide alga on growth, feeding physiology and locomotory behavior of scallop larvae (*Argopecten irradians*)
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 511-541
Publisher: Springer-Verlag
Key words: brown tide, scallop larvae, *Argopecten irradians*, *Aureococcus anophagefferens*, growth, mortality
Summary: Using scallop larvae from a local population (Woods Hole), the authors demonstrated in laboratory experiments that near-bloom concentrations of *Aureococcus anophagefferens* reduced larval growth and survival due to inefficient capture and reduced ingestion rates, the former attributed to cell surface characteristics. The presence of *A. anophagefferens* also hindered ingestion, but not capture, of other, nutritious algal species. Ingestion of *A. anophagefferens* resulted in poor nutrition or toxicity in larval scallops, though assimilation efficiency was good and equal to that for *Isochrysis* sp. Scallop veligers exhibited no swimming behavior indicating recognition of the presence of *A. anophagefferens* as they do with common algal prey such as *Isochrysis* sp.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Scott M. Gallager
Source Inst.: Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA

Author: Gallegos, S.
Date: 1990
Dissertation: Evaluation of the potential of the NOAA-n AVHRR reflective data in oceanography
Pages: 189 pp.
Source: Department of Oceanography, Texas A & M University, College Station, TX, USA
Key words: reflective data, advanced very high resolution radiometry, phytoplankton, satellite observation, atmospheric effect, albedo, pixel, Coastal Zone Color Scanner, pigment, red tide
Summary: The organic and physical features of the ocean surface as seen synoptically can provide clues to the interactions of those processes governing the ocean. Two satellite data bases (the NOAA-n Advanced Very High Resolution Radiometer and the Coastal Zone Color Scanner data) provide the means to compare information on sea surface phytoplankton concentrations and circulation patterns over a broad area. *In situ* data taken during a Florida red tide in 1983 and a Texas red tide in 1986 serve to evaluate the relative capabilities of the two satellite data sources.
Methods: See "Materials and Methods."
QA/QC: N/A (Physical oceanography)

Contact: Sonia Gallegos
Source Inst.: Center for Space Research, The University of Texas at Austin, Austin, TX, USA

Author: Gates, J. A. and Wilson, W. B.
Date: 1960
Title: The toxicity of *Gonyaulax monilata* Howell to *Mugil cephalus*
Journal: *Limnol. Oceanogr.* 5(2):171-174
Key words: *Gonyaulax monilata*, *Mugil cephalus*, dinoflagellate, toxin, Galveston, Texas, red tide
Summary: "Young" mullet (*Mugil cephalus*) subjected to *in vitro* cultures of the marine red tide dinoflagellate *Gonyaulax monilata* suffered mortality within 4.5 hours in all aliquots except the uninoculated control medium. The authors conclude that a toxic substance produced by *Gonyaulax monilata* was the causative agent.
Methods: See "Methods and Materials."
QA/QC: None *per se*; see "Methods and Materials."
Contact: William B. Wilson
Source Inst.: U. S. Fish and Wildlife Service, Galveston, Texas, USA

Author: Geesey, M. and Tester, P. A.
Date: 1993
Title/Ch.: *Gymnodinium breve*: ubiquitous in Gulf of Mexico waters?
Book: *Toxic Phytoplankton Blooms in the Sea*, Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton
Editor: T. J. Smayda and Y. Shimizu
Pages: 251-255
Publisher: Elsevier
Key words: *Gymnodinium breve*, Gulf of Mexico, *Ptychodiscus brevis*, red tide, bloom
Summary: A common source of red tide off the west coast of Florida, *Gymnodinium breve* is found throughout the Gulf of Mexico, but, until this study, its cell density in nearshore and offshore waters of various depths was largely unknown. Over twelve months (3/90-3/91), NOAA vessels sampled 61 stations throughout the Gulf of Mexico from depths of 0 to >150 m. Density in shallow, well-mixed waters was constant, but in deeper waters with a thermocline, *G. breve* was more abundant near the surface. Concentrations in central Gulf waters remained at <10 cells/ml throughout the year. Coastal stations generally registered the highest densities at 100 cells/ml.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Pat Tester
Source Inst.: National Marine Fisheries Service, NOAA, Southeast Fisheries Science Center, Beaufort Laboratory, Beaufort, NC 28516 USA

Author: Gunter, G.
Date: 1951
Title: Mass mortality and dinoflagellate blooms in the Gulf of Mexico

Journal: *Science* 113:250-251
Key words: fish mortality, dinoflagellate, bloom, Gulf of Mexico, Florida, Texas, *Gonyaulax*, Offats Bayou
Summary: In this lengthy letter to the editors of *Science*, the author offers some criticism for an article by Connell and Cross in a previous volume in which the two stated that a recent case of fish mortality in Offats Bayou, a branch of Galveston Bay, was likely due to a red tide of *Gonyaulax* sp. In addition, Gunter added some historical and scientific data from what little was known of red tides at that time.
Methods: None (Letter to editor)
QA/QC: N/A
Contact: N/A
Source Inst.: Marine Science Institute, The University of Texas, P. O. Box 1267, Port Aransas, TX 78373-1267 USA

Author: Gunter, G., Smith, F. G. W., and Williams, R. H.
Date: 1947
Title: Mass mortality of marine animals on the lower west coast of Florida, November 1946-January 1947
Journal: *Science* 105:256-257
Key words: fish mortality, Florida, Gulf of Mexico, discolored water, plankton,
Summary: From reports of an "odorless but acrid gas" that produced respiratory irritation in an area of heavy surf, the discolored water and corresponding fish kills that occurred off the Gulf Coast of South Florida from November of 1946 to January of 1947 was due to *Gymnodinium breve*, though this article did not identify the organism to species.
Methods: None (report)
QA/QC: N/A
Contact: University of Miami, Coral Gables, Florida, USA
Source Inst.: Same

Author: Haddad, K. D. and Carder K. L.
Date: 1979
Title/Ch.: Oceanic intrusion: one possible initiation mechanism of red tide blooms on the west coast of Florida
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 269-274
Publisher: Elsevier/North-Holland, Inc.
Key words: red tide, bloom, Florida, upwelling, Loop Current, cyst, excystment, growth
Summary: The authors suggest that the Loop Current's intrusion onto the west Florida shelf may resuspend the resting cysts of *Gymnodinium breve* and create conditions conducive to excystment and growth. Such conditions include decreased temperature, increased light availability and increased nutrients.
Methods: N/A (Published hypothesis)
QA/QC: N/A

Contact: Kenneth D. Haddad
Source Inst.: Department of Marine Science, University of South Florida, 830 First Street South, St. Petersburg, FL 33701 USA

Author: Hallegraeff, G. M.
Date: 1993
Title: A review of harmful algal blooms and their apparent global increase
Journal: *Phycologia* 32(2):79-99
Key words: bloom, red tide, aquaculture, eutrophication, climate, transport, dinoflagellate, cyst, ballast water, shellfish
Summary: This review presents evidence for an apparent increase in problem algal blooms in recent years, though it does not claim to ascribe the trend to an actual increase or to steadily improving means and efforts to detect blooms. Increased recreational, commercial and aquacultural use of coastal waters, however, have yielded more problems with negative public health and economic impacts from harmful algal blooms. As a result, the author urges the scientific community to respond to the problem by making efforts to prevent the spread of harmful algae from the areas where they are indigenous to other novel and vulnerable areas throughout the world and to make public officials aware of policies to prevent or ameliorate the negative impacts of blooms. The possible impacts of global warming, ozone depletion, El Nino events, eutrophication and ballast water transport must be studied with respect to their possible stimulation of blooms.
Methods: None (review)
QA/QC: N/A
Contact: G. M. Hallegraeff
Source Inst.: Department of Plant Science, University of Tasmania, GPO Box 252C, Hobart, Tasmania 7001, Australia

Author: Hallegraeff, G. M. and Bolch, C. J.
Date: 1992
Title: Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture
Journal: *Journal of Plankton Research* 14(8):1067-1084
Key words: diatom, dinoflagellate, cyst, ballast water, aquaculture, sediment, *Gymnodinium*, *Alexandrium*, bloom, quarantine
Summary: Non-endemic diatoms and dinoflagellates may be introduced to novel regions when cargo ships with cyst-contaminated ballast water and associated sediments discharge their ballast water in port. Fifty percent of sediment samples taken from 343 cargo vessels in 18 Australian ports revealed dinoflagellate resting spores (cysts); these spores represented at least 53 species, 20 of which were successfully germinated in the laboratory. Cysts of toxic dinoflagellates of the genera *Alexandrium* and *Gymnodinium* were found in 16 ships, one of which contained an estimated >300 million viable *A. tamarense* cysts. To counter the threat from toxic species, the authors suggest several ways to lessen or prevent the spread of cysts from ballast water discharge.
Methods: See "Method."

QA/QC: None *per se*; see "Method."
Contact: G. M. Hallegraeff
Source Inst.: Department of Plant Science, University of Tasmania, GPO Box 252C, Hobart, Tasmania 7001, Australia

Author: Harper, D. E., Jr. and Guillen, G.
Date: 1989
Title: Occurrence of a dinoflagellate bloom associated with an influx of low salinity water at Galveston, Texas, and coincident mortalities of demersal fish and benthic invertebrates
Journal: *Contributions in Marine Science* 31:147-161
Key words: dinoflagellate, bloom, Galveston, Texas, Atlantic threadfin, *Polydactylus octonemus*, hypoxia, hydrogen sulfide
Summary: Attempting to correlate hydrographic data with dinoflagellate bloom occurrence to understand the sequence of events leading to the bloom, the authors noted the correspondence of low salinity water with bloom appearance off Galveston, Texas in early June 1984. The low salinity was likely due to high discharge from the Mississippi-Atchafalaya Rivers in preceding months and a wind-driven current down the Texas coast. Within a week, a die-off of the demersal Atlantic threadfin (*Polydactylus octonemus*) occurred, probably due to hypoxia and/or hydrogen sulfide production as a result of nocturnal dinoflagellate metabolism and anaerobic decay of dead dinoflagellate cells.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Donald E. Harper, Jr.
Source Inst.: Texas A & M Marine Laboratory, 5007 Avenue U, Galveston, TX 77551 USA

Author: Hemmert, W. H.
Date: 1975
Title/Chap.: The public health implications of *Gymnodinium breve* red tides, a review of the literature and recent events
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 489-497
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: public health, *Gymnodinium breve*, red tide, dinoflagellate, Florida, neurotoxic shellfish poisoning (NSP), respiratory irritation, contact irritation, hemtologic pathology, toxin
Summary: The author found the scientific literature depauperate on the public health problems caused by *G. breve* and similar organisms. Southwest Florida's major *G. breve* red tide event of 1973-74 revealed three major public health concerns and a possible fourth: neurotoxic shellfish poisoning (NSP), respiratory irritation, contact irritation and hematologic pathology. Eleven people were apparently stricken with NSP, though none fatally. Clinical reactions to airborne toxins constituted a

respiratory irritation that disappeared upon departure from the affected area. Also temporary was the contact irritation (mild dermatitis, if any, and/or mild to severe conjunctivitis) experienced by people exposed to the toxin while in the water; severity of conjunctivitis correlates with intensity of exposure. Only the potential for decreased blood coagulation exists for humans.

Methods: None (report)
QA/QC: N/A
Contact: Wynn H. Hemmert
Source Inst.: Bureau of Preventable Diseases, Florida State Division of Health, Jacksonville, Florida, USA

Author: Hofmann, E. E., and Worley, S. J.
Date: 1986
Title: An investigation of the circulation of the Gulf of Mexico
Journal: *Journal of Geophysical Research* 91(C12):14,221-14.236
Key words: circulation, Gulf of Mexico, hydrography, density, Loop Current, mesoscale eddy, Antarctic Intermediate Water, velocity profile, gyre, transport
Summary: Reanalysis of historic hydrographic data on winter circulation in the Gulf of Mexico revealed that the large-scale circulation is heavily influenced by an anticyclonic gyre in the upper 500 m. Additional influences come from the Loop Current in the eastern gulf and a cyclonic eddy in the northwestern gulf, and the transports estimated for these circulation features concur with estimates from other hydrographic studies in the gulf.
Methods: See "Methods."
QA/QC: N/A (Physical oceanography)
Contact: Eileen F. Hofmann
Source Inst.: Department of Oceanography, Texas A & M University, College Station, TX, USA

Author: Howell, J. F.
Date: 1953
Title: *Gonyaulax monilata*, sp. nov., the causative dinoflagellate of a red tide on the east coast of Florida in August-September, 1951
Journal: *Transactions of the American Microscopical Society* 72:153-156
Key words: *Gonyaulax monilata*, dinoflagellate, red tide, Florida, plankton, Offatts Bayou, Galveston, Texas
Summary: Using samples mainly from the Indian and Banana Rivers on Florida's east coast, the author described a small dinoflagellate species known to form chains of up to 40 cells in length. Some doubt was expressed as to whether it was appropriate to assign the species to the Genus *Gonyaulax* because the prevalent generic description allowed "no variation in the number of precingular plates" and the organism exhibited radically different thecal suture patterns when compared to *G. catenella*. In early September of 1952, the author found identical chain-forming dinoflagellates in a sample taken from Offatts Bayou, near Galveston, Texas.
Methods: None (taxonomic description/classification)
QA/QC: N/A

Contact: John F. Howell
Source Inst.: U. S. Fish and Wildlife Service, Fort Crockett, Galveston, Texas, USA

Author: Huntley, M., Sykes, P., Rohan, S. and Marin, V.
Date: 1986
Title: Chemically-mediated rejection of dinoflagellate prey by the copepods *Calanus pacificus* and *Paracalanus parvus*: mechanism, occurrence and significance
Journal: *Marine Ecology Progress Series* 28:105-120
Key words: dinoflagellate, copepods, *Ptychodiscus brevis*, *Calanus pacificus*, *Paracalanus parvus*, particle rejection, bloom, chemical defense, growth rate
Summary: Thirteen species of dinoflagellates were used as possible prey for two species of copepods in a large suite of experiments. Results of one experiment included *Ptychodiscus brevis* (now called *Gymnodinium breve*, a source of neurotoxic shellfish poisoning) as one of several dinoflagellates consistently rejected by the copepod *Calanus pacificus*. Ingestion of *P. brevis* cells produced elevated heart rate and loss of motor control in the copepod. Not only do noxious dinoflagellate species such as *P. brevis* gain an interspecific competitive advantage in survival over edible species, they also seem far more likely to be able to maintain bloom proportions in spite of zooplankton grazers when other factors are favorable.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: M. Huntley
Source Inst.: Scripps Institution of Oceanography, A-002, La Jolla, California 92093 USA

Author: Jensen, A. C.
Date: 1975
Title/Ch.: The economic halo of a red tide
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 507-516
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: red tide, economics, New England, *Gonyaulax tamarensis*, fishing industry, public health, shellfish, halo effect, seafood, seafood industry
Summary: An economic halo effect from the 1972 New England red tide of *Gonyaulax tamarensis* (source of potentially lethal paralytic shellfish poisoning or PSP) appeared in the form of consumer resistance to canned shellfish and finfish products. Shortly after shellfish that had been harvested in New England waters were removed from the market as a safety measure, consumers in states outside of New England refused to buy canned seafood regardless of where it had been harvested, hurting the seafood industries of states untouched by the red tide. The author concludes with a discussion of the necessary informational system needed to counter the rumors and misinformation that can cause economic havoc for industries both suffering from and falsely associated with toxic red tide blooms.
Methods: None (report)
QA/QC: N/A

Contact: Albert C. Jensen
Source Inst.: Division of Marine and Coastal Resources, New York State Department of Environmental Conservation, State University of New York at Stony Brook, Stony Brook, New York 11794 USA

Author: Jensen, D. A. and Bowman, J.
Date: 1975
Title: On the occurrence of the "red tide" *Gonyaulax monilata* in the Corpus Christi Inner Harbor (July-September 1975)
Pages: 20 pp.
Source: Texas Water Quality Board, District 12
Key words: red tide, *Gonyaulax monilata*, Corpus Christi, Texas, bloom, dinoflagellate, cyst, fish kill, iron, *Eutreptia* c. f. *lanowii*
Summary: The maximum recorded density of a bloom of *Gonyaulax* (now *Alexandrium*) *monilata* in the Corpus Christi Inner Harbor turning basin was noted when it was first detected by routine monitoring on 22 July 1975. Thereafter, cell concentrations and the number/length of chains decreased until no red tide was detected on 17 September. Despite relatively low cell concentrations, a fish kill occurred in the turning basin on 22 August. The most prominent correlation between nutrient and cell concentration concerned iron, which peaked and declined with the bloom. A "green tide" occurred immediately after the red tide disappeared, identified as the euglenoid *Eutreptia* c. f. *lanowii*. Benthic cysts are suggested as the means by which the bloom appeared deep within the inner harbor, though the document offers no evidence of cyst presence.
Methods: See "Methods and Materials."
QA/QC: None *per se* but for modified Winkler dissolved oxygen analysis (USEPA, 1974)
Contact: James Bowman, Jr.
Source Inst.: Texas Natural Resource Conservation Commission, Field Operations Division, Environmental Assessment Program, 4410 Dillon Lane, Suite 47, Corpus Christi, TX 78415-5326 USA

Author: Joyce, E. A., Jr., and Roberts, B. S.
Date: 1975
Title/Chap.: Florida Department of Natural Resources Red Tide Research Program
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 95-103
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: red tide, Florida, initiation, nutrition, *Gymnodinium breve*, maintenance, transport, toxin, life cycle, seed bed
Summary: About 30 red tides had been reported in Florida waters since 1844, but research on causes began only in the early 1950's. That research, sponsored by the Florida Department of Natural Resources (FDNR) centered on *Gymnodinium breve* and dealt with location of bloom initiation, nutrition, hydrologic and meteorologic influences on bloom maintenance and transport, effects on offshore patch reef

biota and inshore shellfish beds, taxonomy and ecology of associated phytoplankton and bloom prediction. FDNR research at time of publication emphasized the study of *G. breve* life cycles, the search for offshore seed beds, toxin longevity and effects on marine life, fisheries repopulation and carcass salvage, and evaluation of land discharges on bloom growth. The research design emphasized prediction and public education and reduction of negative economic impact.

Methods: None (report)
QA/QC: N/A
Contact: Edwin A. Joyce, Jr.
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Science and Technology, Tallahassee, Florida, USA

Author: Keller, A. A. and Rice, R. L.
Date: 1989
Title: Effects of nutrient enrichment on natural populations of the brown tide phytoplankton *Aureococcus anophagefferens* (Chrysophyceae)
Journal: *J. Phycol.* 25:636-646
Key words: brown tide, phytoplankton, *Aureococcus anophagefferens*, Chrysophyceae, diatoms, mesocosm, Narragansett Bay, Rhode Island, picoalgae, dissolved inorganic nitrogen
Summary: Approximately equal populations of the brown tide picoalga *Aureococcus anophagefferens* in twelve 13,000 L mesocosms were exposed to varying levels of nutrients Densities in untreated systems were similar to the increased abundances of *A. anophagefferens* in Narragansett Bay (2.6 x 10^9 cells/L max.), the seawater source for the mesocosms. Nutrient addition tanks also had blooms, but they were brief in duration and did not long remain at densities above the usual level for eukaryotic algae in the bay. Diatom abundance increased in all nutrient-treated tanks; that plus a significant inverse correlation between dissolved inorganic nitrogen (DIN) levels and mean picoalgae abundance revealed that the brown tide can grow at DIN levels known to limit diatom growth.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Aimee A. Keller
Source Inst.: Graduate School of Oceanography, University of Rhode Island Bay Campus, South Ferry Road, Narragansett, Rhode Island 92882-1197 USA

Author: Keller, M. D., Bellows, W. K. and Guillard, R. R. L.
Date: 1989

Title/Ch.: Dimethylsulfide production and marine phytoplankton: an additional impact of unusual blooms
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter

Pages: 101-115
Publisher: Springer-Verlag
Key words: dimethylsulfide, DMS, phytoplankton, bloom, dimethylsulfoniopropionate, DMSP, acrylic acid
Summary: Though *Aureococcus anophagefferens* is only mentioned twice among the numerous other phytoplankton species responsible for greater or lesser degrees of DMS release, this paper explains the basic mechanism for that release, its general environmental effect, and the relative contributions to release by specific phytoplankton of twelve classes. *A. anophagefferens*, as an alga possessing chlorophyll *a* and *c*, is grouped with other chrysophytes and diatoms as DMS producers of species-specific variability, producing less than dinoflagellates and prymnesiophytes, but significantly more than chlorophytes, cryptomonads and cyanobacteria.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Maureen D. Keller
Source Inst.: Bigelow Laboratory for Ocean Sciences, McKown Point, West Boothbay Harbor, Maine 04575 USA

Author: Kuenstner, S. H.
Date: 1988
Thesis: The effects of the "brown tide" alga on the feeding physiology of *Argopecten irradians* and *Mytilus edulis*
Pages: 84 pp.
Source: Marine Environmental Sciences Program, SUNY at Stony Brook
Key words: brown tide, *Argopecten irradians*, *Mytilus edulis*, *Aureococcus anophagefferens*, bloom, chrysophyte, retention efficiency, clearance rate, absorption efficiency, starvation
Summary: This study was prompted by brown tide-induced weight loss in adult bay scallops and recruitment failure during the bloom of 1985. The author studied the feeding mechanism of bay scallops (*Argopecten irradians*) and mussels (*Mytilus edulis*) to determine the adverse effects of the brown tide alga *Aureococcus anophagefferens* on both bivalves. Scallops had a lower retention efficiency (36%) than mussels (59%) when both grazed on *A. anophagefferens*. Juvenile scallops and mussels had higher clearance rates for the alga *Thalassiosira weissflogii* than *A. anophagefferens*, but both bivalves can digest both algae with 90% efficiency when the algae are at low concentrations. Using physiological data to construct an energy budget for scallops exposed to the brown tide, the results over the short-term could not explain the bivalve starvation observed in the field. Chronic exposure, therefore, may have been the key to negative growth during the Long Island brown tide bloom of 1985.
Methods: See "Methods and Materials," pp. 16-31.
QA/QC: See "Methods and Materials."
Contact: V. Monica Bricelj
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794-5000 USA

Author: Lowe, J. A., Farrow, D. R. G., Pait, A. S., Arenstam, S. J., and Lavan, E. F.
Date: 1991
Title: *Fish kills in coastal waters*
Pages: pp. 60-61
Publisher: National Oceanic and Atmospheric Administration
Key words: fish, fish-kill, coast, Gulf of Mexico, Texas, red tide
Summary: Only one table on p. 61 of this report categorizes fish kills due to red tide in Texas from 1980-89, indicating that less than 100 fish died as a result of eight reported red tide events. [This report is in direct conflict with documented observational evidence of far greater fish mortality ranging from Galveston Island to south of the Padre Island National Seashore during the period from late August to late October 1986. See Trebatoski (1988), among others, listed below.]
Methods: None (government report).
QA/QC: N/A
Contact: Strategic Environmental Assessments Division, Office of Ocean Resources Conservation and Assessment, National Ocean Service
Source Inst.: National Oceanic and Atmospheric Administration

Author: Lund, E. J.
Date: 1936
Title/Ch.: Some facts relating to the occurrences of dead and dying fish on the Texas coast during June, July, and August, 1935
Source: *Annual Report of the Texas Game, Fish and Oyster Commission, 1934-35*
Pages: 47-50
Publisher: Texas Game, Fish and Oyster Commission
Key words: fish [mortality], Texas, [aerosol irritant], menhaden, mullet, [red tide], [*Gymnodinium breve*]
Summary: This report contains information on a massive fish kill in the summer of 1935, ranging from near Port Aransas (St. Joseph Island) to points from 150 to 200 miles south. Menhaden and mullet made up the largest percentage of the estimated 2 million pounds of dead fish that washed ashore in July and August, accompanied by at least a dozen other fish species. On several instances, observers reported experiencing an "irritating 'gas'," a description which is similar to the effects of aerosol irritants from *Gymnodinium breve* toxin. During May and June, prior to the first appearance of fish carcasses, rainfall and river flood levels were unusually high, and on 28 August, the surface water temperature was recorded at 31°C. The author raises those physical factors as potentially important influences on the fish kill, but aside from riverine outflow possibly carrying "heavy inshore plankton growth," he makes no connection between fish mortality and phytoplankton.
Methods: None (Report)
QA/QC: N/A
Contact: Larry McEachron [For access to this literature]
Source Inst.: Texas Parks &Wildlife Department, Coastal Fisheries Division, Rockport, TX 78382 USA

Author: Marvin, K. T.
Date: 1965
Title/Ch.: *Operation and maintenance of salt-water laboratories*
Source: Fishery Research: Biological Laboratory, Galveston, Fiscal Year 1964, Circular 230
Pages: 84-86
Publisher: United States Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries
Key words: East Lagoon (Galveston Bay), plankton, bloom, chlorophyll, *Gonyaulax monilata*, dinoflagellate,
Summary: The USFWS experimental facility in Galveston Bay's East Lagoon had suffered complete mortality of all oyster stock in previous years due to "poisonous plankton blooms" entering the system via the water intake. This led to installation of a recirculating system to temporarily free the system from total dependence on an exterior water source and twice-weekly water analyses for chlorophyll and other constituents. An August 1963 chlorophyll peak was linked to a bloom of the red tide dinoflagellate *Gonyaulax* (now *Alexandrium*) *monilata*. The author indicates that such blooms seem to be seasonal occurrences in East Lagoon.
Methods: None (report)
QA/QC: N/A
Contact: Kenneth T. Marvin, Supervisory Chemist
Source Inst.: Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, USA

Author: Matsuoka, K., Fukuyo, Y. and Anderson, D. M.
Date: 1989
Title/Ch.: Methods for modern dinoflagellate cyst studies
Book: *Red tides: biology, environmental science, and toxicology*. Proceedings of the First International Symposium on Red Tides held November 10-14, 1987, in Takamatsu, Kagawa Prefecture, Japan.
Editor: T. Okaichi, D. M. Anderson and T. Nemoto
Pages: 461-479
Publisher: Elsevier Science Publishing Company, Inc., New York
Key words: dinoflagellate, cyst, sampling, fixation, preservation, isolation, culture, identification, *Gymnodinium breve*, *Alexandrium monilata*
Summary: This manual includes a key for identification of cyst-forming dinoflagellates based on cyst shape and was the backbone for a dinoflagellate cyst workshop held at the symposium. *Gymnodinium breve* and *Alexandrium monilata* are included in the list of all extant cyst-forming dinoflagellates.
Methods: Primarily a methods paper.

QA/QC: None *per se*.
Contact: D. M. Anderson
Source Inst.: Biology Department, Woods Hole Oceanographic Inst., Woods Hole, MA 02543 USA

Author: Milligan, A. J.

Date: 1992
Thesis: An investigation of factors contributing to blooms of the "brown tide" *Aureococcus anophagefferens* (Chrysophyceae) under nutrient saturated (light limited) conditions
Pages: 84 pp.
Source: M. S. Thesis, Department of Marine Environmental Science, State University of New York at Stony Brook
Key words: bloom, brown tide, *Aureococcus anophagefferens*, Chrysophyceae, nutrient saturation, light limitation, Long Island, iron, selenium, nanoplankton
Summary: Following the six-year summer bloom of the brown tide chrysophyte *Aureococcus anophagefferens* in the bays of Long Island, New York, the author tested the hypothesis that *A. anophagefferens* had a greater ability to photoacclimate and maintain high growth rates relative to other phytoplankton. In this attempt, light utilization efficiency, photoacclimation, carbon metabolism and iron/selenium effects were determined for *A. anophagefferens*. The brown tide alga shows good photoacclimation, greater carbon fixation (per unit chlorophyll) and photosynthetic efficiency in fluctuating rather than constant light and enhanced growth with additions of iron but not selenium.
Methods: See "Methods" on pp. 12-20.
QA/QC: None *per se*; see "Methods."
Contact: Elizabeth M. Cosper
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794 USA

Author: Moestrup, O. and Larsen, J.
Date: 1990
Title/Ch.: Some comments on the use of the generic names *Ptychodiscus* and *Alexandrium*
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 78-81
Publisher: Elsevier Science Publishing Co., Inc.
Key words: *Ptychodiscus brevis*, *Gymnodinium*, *Alexandrium*, genus, toxic algae, plankton, taxonomy, paralytic shellfish poisoning (PSP), *Gonyaulax*, flagellates
Summary: The authors argue that the red tide dinoflagellate known as *Ptychodiscus brevis* should not be separated from the genus *Gymnodinium* and that the generic name *Alexandrium* is better suited for PSP-producing species formerly placed within the genus *Gonyaulax*. Upon these recommendations, the proper nomenclature for one of the two red tide algae that have constituted problem blooms in the "Coastal Bend" of the Texas Gulf coast supports the name *Gymnodinium breve*.
Methods: N/A (Comments on taxonomy)
QA/QC: N/A
Contact: O. Moestrup
Source Inst.: Institut for Sporeplanter, Oster Farimagsgade 2D, DK-1353 Kobenhavn K, Denmark

Author: Montagna, P. A., Stockwell, D. A. and Kalke, R. D.
Date: 1993
Title: Dwarf surfclam *Mulinia lateralis* (Say, 1822) populations and feeding during the Texas brown tide event
Journal: *Journal of Shellfish Research* 12(2):433-442
Key words: dwarf surfclam, *Mulinia lateralis*, Texas, brown tide, chrysophyte, algae, Baffin Bay, Laguna Madre, shellfish
Summary: Dwarf surfclam populations perished at the same time that a brown tide bloom occurred in Baffin Bay and Laguna Madre on the Texas Gulf Coast in 1990. In feeding experiments to determine if the shellfish loss was due to negative feeding interactions between the clam and the brown tide, radioactive tracers and an additional three phytoplankton were used. Grazing rates increased with algal concentrations <1000 cells/ml for all of the algal species; grazing rate and assimilation efficiency were unaffected by brown tide cells at higher concentrations. Other factors, therefore, such as reproductive or toxic bloom effects or even non-bloom factors were more likely responsible for the dwarf surfclam population loss. Absence of those filter feeders may have prolonged the duration of the bloom.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Paul A. Montagna
Source Inst.: The University of Texas at Austin, Marine Science Institute, P. O. Box 1267, Port Aransas, TX 78373 USA

Author: New York State Interagency Committee on Aquatic Resources Development
Date: 1986
Title: *Proceedings of the Emergency Conference on "Brown Tide" and Other Unusual Algal Blooms*
Pages: 33 pp.
Publisher: Port Authority of New York and New Jersey
Key words: brown tide, algal bloom, *Aureococcus anorexefferens*, picoplankton, Peconic Bay, Long Island, New York, bay scallop, eel grass
Summary: The destructive brown tide bloom in Long Island bays and similar events in Rhode Island and New Jersey prompted the State of New York to sponsor a conference to examine the problem and possible solutions to it, attended by research scientists with relevant expertise from the region and representatives of government agencies. The report contains abstracts on the characterization of the brown alga (now known as *A. anophagefferens*), culturing, occurrence and distribution, meteorological studies, impacts on shellfish and brown tide effects on eelgrass distribution and abundance.
Methods: N/A (Conference report, though abstracts make some reference to methods)
QA/QC: N/A
Contact: William Wise
Source Inst.: Living Marine Resources Institute, Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794-5000 USA

Author: Nixon, S. W., Granger, S. L., Taylor, D. I., Johnson, P. W. and Buckley, B. A.
Date: 1994
Title: Subtidal volume fluxes, nutrient inputs and the brown tide--an alternate hypothesis
Journal: *Estuarine, Coastal and Shelf Science* 39:303-312
Key words: nutrients, nutrient flux, brown tide, *Aureococcus anophagefferens*, Great South Bay, mesocosms
Summary: This paper agrees that unusual meteorological and hydrological conditions contributed the the 1985 outbreak of brown tide in Long Island bays, but proposes that, with a many-fold greater contribution of nutrients from the coastal ocean relative to land drainage, *A. anophagefferens* achieved bloom proportions because nutrient input was *reduced*, not increased. Evidence from field surveys and mesocosms suggest that oligotrophic waters favor the growth of *A. anophagefferens*.
Methods: N/A (Published hypothesis)
QA/QC: N/A
Contact: S. W. Nixon
Source Inst.: Graduate School of Oceanography, Univeristy of Rhode Island, Narragansett, Rhode Island 02882-1197 USA

Author: Nuzzi, R. and Waters R. M.
Date: 1989
Title/Ch.: The spatial and temporal distribution of "brown tide" in eastern Long Island
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 117-137
Publisher: Springer-Verlag
Key words: distribution, brown tide, Long Island, bloom, phytoplankton, *Aureococcus anophagefferens*
Summary: The Suffolk County Department of Health Service's "Bureau of Marine Resources" reports on its investigations into the distribution of the brown tide from 1986-1988. Areas affected by brown tide, the Peconic Bay estuary and the South Shore bays as seen during aerial surveys, remained relatively constant, and both unusually large and persistent over the three years covered by this study. Brown tide abundance seemed to be unlinked to macronutrient concentrations in the affected areas, with regional meterorological conditions a more likely catalyst, particularly rainfall fluctuations. Micronutrient concentrations in bloom waters may also be a principal agent of bloom formation.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods" and "Results."
Contact: Robert Nuzzi
Source Inst.: Suffolk County Department of Health Services, Evans K. Griffing County Center, Riverhead, New York 11901 USA

Author: Olsen, P. S.
Date: 1989

Title/Ch.: Development and distribution of a brown-water algal bloom in Barnegat Bay, New Jersey with perspective on resources and other red tides in the region
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 189-212
Publisher: Springer-Verlag
Key words: brown-water, bloom, Barnegat Bay, new Jersey, red tide, phytoplankton, *Aureococcus anophagefferens*, picoplankton
Summary: The authors conducted a 1987 survey of a persistent yellow-brown algal bloom in Barnegat Bay, New Jersey, that had returned in high density every summer since 1985, seeking to accurately characterize the responsible picoplankton and reveal potential similarities between it and the simultaneous brown tide in Long Island and the New York Bight region. The 2-3 µm coccoid alga at densities as high as several times 10^6 cells/ml could not be identified as a common bloom-producing chlorophyte nor the chrysophyte *Aureococcus anophagefferens*, among others, and greatly reduced algal diversity at peak bloom. High densities seldom coincided with chlorophyll maxima, but a trend of higher numbers with increasing salinity was observed. Unofficial reports of reduced eelgrass survival and sportfishing catches came from areas affected by the bloom.
Methods: See “Methods.”
QA/QC: None *per se*; see “Methods.”
Contact: Paul S. Olsen
Source Inst.: New Jersey State Dept. of Environmental Protection, Division of Water Resources, Geological Survey, CN 029, Trenton, New Jersey 08625 USA

Author: Perry, H. M., Stuck, K. C., and Howse, H. D.
Date: 1979
Title: First record of a bloom of Gonyaulax monilata in coastal waters of Mississippi
Journal: *Gulf Research Reports* 6(3):313-316
Key words: bloom, *Gonyaulax* [*Alexandrium*] *monilata*, Mississippi Sound, dinoflagellate, Gulf of Mexico, red tide
Summary: Aerial surveys and water samples were performed during a widespread bloom of the armored dinoflagellate *Gonyaulax* [now *Alexandrium*] *monilata* in Mississippi Sound as well as Alabama and Florida. The bloom persisted in Mississippi Sound from about 8 August until the advent of Hurricane Frederic on 11 September (1979). During the bloom, surface temperatures ranged from 30.0 to 30.8°C. Salinities were below normal in Mississippi Sound due to previous heavy rains and ranged from 24.0 to 26.0 ppt. The maximum cell count reached 1.65×10^7 cells/liter on 22 August. Pensacola Bay, Florida, had the maximum cell density for that state of 3.18×10^7 cells/liter on 15 August, when water temperature was 28.0°C and salinity only 14.0 ppt.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Harriet M. Perry

Source Inst.: Fisheries Research and Development, Gulf Coast Research Laboratory, Ocean Springs, MS 39564 USA

Author: Pierce, R. H., Henry, M. S., Proffitt, L. S. and Hasbrouck, P. A.
Date: 1990
Title/Ch.: Red tide toxin (brevetoxin) enrichment in marine aerosol
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 128-131
Publisher: Elsevier
Key words: red tide, toxin, brevetoxin, aerosol, dinoflagellate, *Ptychodiscus brevis*
Summary: Knowing that marine aerosols can carry brevetoxins, the authors measured the level of toxin enrichment in aerosols created in the laboratory versus original culture concentrations. A total of six toxins were detected in both culture and aerosol, enriched by 5 to 50 times in the aerosol relative to the culture.
Methods: See "Methods and Materials."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Richard H. Pierce
Source Inst.: Mote Marine Laboratory, 1600 City Island Park, Sarasota, FL 34236 USA

Author: Proctor, R. R., Jr.
Date: 1965
Title/Ch.: Special Report: *Biological Indicators in East Lagoon, Galveston Island*
Source: Fishery Research: Biological Laboratory, Galveston, Fiscal Year 1964, Circular 230
Pages: 87-88
Publisher: United States Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries
Key words: East Lagoon, [Galveston Bay], oyster, oyster mortality, *Gonyaulax monilata*, [red tide, dinoflagellate], bloom
Summary: The author reports on the first two years of a study by the Bureau of Commercial Fisheries to determine if water in the East Lagoon was suitable for oyster culture. An August, 1963 bloom of *Gonyaulax* [now *Alexandrium*] *monilata* compelled the transfer of oysters kept in East Lagoon into the laboratory tank with a corresponding group of oysters kept there and the conversion of the tank circulation to a closed, recirculating system. Both oyster groups still suffered mortality thereafter (10 of the lagoon group's original 25 oysters; 2 out of 25 in the laboratory group); the author suggests that *G. monilata* cells were in the recirculated water and caused the mortality. The bloom ceased in the lagoon after about two weeks, and the lagoon oysters were returned to the field. No further mortality was associated with *G. monilata*.
Methods: None (report)
QA/QC: N/A
Contact: Raphael R. Proctor, Jr., Chemist
Source Inst.: Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, USA

Author: Proctor, R. R., Jr.
Date: 1966
Title/Ch.: Special Report: *Oyster growth experiment in East Lagoon*
Source: Annual Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, Fiscal Year 1965, Circular 246
Pages: 48-49
Publisher: United States Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries
Key words: oyster, oyster mortality, East Lagoon, [Galveston Bay], *Gonyaulax monilata*, [dinoflagellate, red tide]
Summary: The author states that conditions in a USFWS lagoon and the associated lagoon laboratory are suitable only for short-term oyster experiments due to a common oyster disease caused by *Dermocystidium marinum* and apparent annual (summer) blooms with subsequent oyster mortality due to the red tide dinoflagellate *Gonyaulax* [now *Alexandrium*] *monilata*.
Methods: None *per se* (special report)
QA/QC: N/A
Contact: R. R. Proctor, Jr., Chemist
Source Inst.: Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, USA

Author: Quick, J. A., Jr., and Henderson, G. E.
Date: 1975
Title/Chap.: Evidences of new ichtyointoxicative phenomena in *Gymnodinium breve* red tides
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 413-422
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: ichthyotoxin, *Gymnodinium breve*, red tide, dinoflagellate, Florida, fishes, distress behavior, necropsy, neurointoxication, chronic tissue damage
Summary: The west coast of Florida's peninsula suffered an extended red tide from October 1973 through June 1974. Necropsies were performed as quickly as possible on 129 fish of fifteen genera and species that were either severely distressed or freshly dead at time of collection. Sixteen pathologies were consistently observed; some fish perished due to neurointoxication, whereas other species succumbed to chronic tissue damage. General symptoms were dehydration, hemolysis and disrupted blood clotting mechanisms. Distress behavior was marked and could well be diagnostic for some species.
Methods: See "Methods and Materials."
QA/QC: None *per se*; see "Methods and Materials."
Contact: J. A. Quick, Jr.
Source Inst.: Florida Department of Natural Resources, Marine Research laboratory, St. Petersburg, Florida, USA

Author: Ray, S. M. and Wilson, W. B.

Date: 1957
Title: Effects of unialgal and bacteria-free cultures of *Gymnodinium brevis* on fish , and notes on related studies with bacteria
Journal: USFW Service *Fishery Bulletin* 123(57):469-496
Key words: unialgal culture, *Gymnodinium brevis*, fish, bacteria, dinoflagellate, Gulf of Mexico, red tide, toxin
Summary: With a goal to (1) conduct a laboratory study complementary to field studies of marine animal mortality due to *Gymnodinium brevis* red tide [sp. now referred to as *G. breve*] and (2) increase understanding of why such mass mortalities occur, the authors used unialgal and bacteria-free *G. brevis* cultures to test for toxic effects on fish. Given that fish mortality in bacteria-free cultures did not differ in toxicity from unialgal cultures, the authors concluded that *G. brevis* does produce a toxic substance directly responsible for mass mortality of marine animals during blooms in the Gulf of Mexico. Furthermore, this substance does not lose toxicity with the death or even the absence of the *G. brevis* cells. The six fish species tested were differentially sensitive to the toxin.
Methods: See methods described within the body of the paper with respect to each experiment.
QA/QC: None *per se*; see the descriptions of methods in the body of the paper.
Contact: Sammy M. Ray
Source Inst.: Marine Laboratory, Texas A & M University, Galveston, TX

Author: Ray, S. M. and Aldrich, D. V.
Date: 1967
Title/Ch.: Ecological interactions of toxic dinoflagellates and molluscs in the Gulf of Mexico
Book: *Animal Toxins*
Editor: F. Russell and P. Saunders
Pages: 75-83
Publisher: Pergamon Press, NY
Key words: toxin, dinoflagellate, mollusc, Gulf of Mexico, *Gymnodinium breve*, *Gonyaulax monilata*, Florida, Texas
Summary: The authors investigate several hypotheses as to why red tide dinoflagellates in the Gulf of Mexico have not caused comparable harm to its large shellfish industry as other species have to those of the Atlantic and Pacific coasts. Cultures of *Gymnodinium breve* and *Gonyaulax monilata* [preferably called *Alexandrium monilata*], both Gulf species responsible for fish kills, were introduced into oyster cultures. The oysters were then fed to chicks, but poisoning in the chicks only occurred with *G. breve*. Oysters and other shellfish did not filter when exposed to *G. monilata* in laboratory culture, a behavior apparently identical to wild populations exposed to natural *G. monilata* blooms *in situ*. Differing toxic effects between the two dinoflagellates were observed in molluscs, a polychaete and fish. *G. breve* blooms may be too infrequent to severely affect commercial shellfish in the Gulf, and Gulf shellfish avoid any negative effects of *G. monilata* by not filtering.
Methods: See “Materials and Methods.”
QA/QC: None *per se*; see “Materials and Methods.”

Contact: Sammy M. Ray
Source Inst.: Marine Laboratory, Texas A & M University, Galveston, TX

Author: Riley, C. M., Holt, S. A., Holt, G. J., Buskey, E. J. and Arnold, C. R.
Date: 1989
Title: Mortality of larval red drum (*Sciaenops ocellatus*) associated with a *Ptychodiscus brevis* red tide
Journal: *Contributions in Marine Science* 31:137-146
Key words: larvae, red drum, *Sciaenops ocellatus*, dinoflagellate, *Ptychodiscus brevis*, red tide, Texas, recruitment
Summary: *Ptychodiscus brevis*, preferably known as *Gymnodinium breve*, is a red tide dinoflagellate that can cause paralysis and death in laboratory-spawned and wild-caught red drum larvae at all concentrations above 40 cells/ml. A fall outbreak of this red tide on the Texas Gulf coast in 1986 achieved average peak densities of 7000 cells/ml, but concentrations of almost 5×10^4 cells/ml were detected in isolated patches in bays near Port Aransas throughout October. Red tide blooms of this sort can reduce red drum recruitment during spawning periods.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Cecelia M. Riley
Source Inst.: University of Texas at Austin, Marine Science Institute, Port Aransas, TX 78373-1267

Author: Roberts, B. S.
Date: 1979
Title/Ch.: Occurrence of *Gymnodinium breve* red tides along the west and east coasts of Florida during 1976 and 1977
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 199-202
Publisher: Elsevier/North-Holland, Inc.
Key words: *Gymnodinium breve*, red tide, Florida, bloom
Summary: Red tides in 1976 and 1977 were analyzed with regard to their most likely means of initiation, support and maintenance, all three progressing in a predictable fashion. In 1976, for instance, surface concentrations of *G. breve* increased gradually offshore, were then transported inshore and, after winds induced movement to the south, gradually dissipated. Movement and increased concentrations could be attributed to winds and currents.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Beverly S. Roberts
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. S. E., St. Petersburg, FL 33701 USA

Author: Roberts, B. S., Henderson, G. E. and Medlyn, R. A.

Date: 1979
Title/Ch.: The effect of *Gymnodinium breve* toxin(s) on selected mollusks and crustaceans
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 419-424
Publisher: Elsevier/North-Holland, Inc.
Key words: *Gymnodinium breve*, toxin, mollusk, crustacean, *Fasciolaria hunteria*, *Melongena corona*, *Oliva sayana*, *Callinectes sapidus*, *Menippe mercenaria*, red tide
Summary: The toxin or toxins of the red tide dinoflagellate *Gymnodinium breve* adversely affected three species of mollusks (*Fasciolaria hunteria*, *Melongena corona* and *Oliva sayana*) when directly exposed to *G. breve* toxins (55-69% mortality over 48 hrs.), but had no affect on two species of crustacean (*Callinectes sapidus* and *Menippe mercenaria*) when all crab species were fed toxic clam meat. Along with a lack of any mortality, the crab tissue, upon analysis, showed no accumulation of the toxin.
Methods: See "Methods and Materials."
QA/QC: None *per se*; see "Methods and Materials."
Contact: Beverly S. Roberts
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. S. E., St. Petersburg, FL 33701 USA

Author: Roszell, L. E., Schulman, L. S. and Baden, D. G.
Date: 1990
Title/Ch.: Toxin profiles are dependent on growth stages in cultured *Ptychodiscus brevis*
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 403-406
Publisher: Elsevier
Key words: toxin, growth, *Ptychodiscus brevis*, red tide, dinoflagellate
Summary: Characterization from over 3000 liters of batch cultures of the various toxins, all very similar, produced by *Ptychodiscus brevis* (now known as *Gymnodinium breve*) during logarithmic, stationary and declining phases of population growth reveals that the eight possible toxins appear individually or in combination at different times in the life of a population. What the authors do not suggest but what seems obvious is extension of these findings to characterization of the overall growth stage of blooms *in situ*.
Methods: See "Experimental" and "Results."
QA/QC: None *per se*; see "Experimental."
Contact: Laurie E. Roszell
Source Inst.: University of Miami Rosenstiel School of Marine and Atmospheric Science, Division of Biology and Living Resources, 4600 Rickenbacker Causeway, Miami, FL 33149 USA

Author: Rounsefell, G. A., and Nelson, W. R.

Date: 1966
Title: *Red-tide research summarized to 1964 including an annotated bibliography*
Pages: 85 pp.
Source: United States Fish and Wildlife Service Special Scientific Report, Fisheries No. 535, Washington, D. C.
Key words: red tide, Florida, bloom, mortality, plankton, dinoflagellate, toxic, *Gymnodinium breve*, Gulf of Mexico, Texas
Summary: Using published and unpublished data, the authors summarize the status of red tide research in Florida up to 1964, listing 292 references with some annotations, and discuss the influence of oceanographic conditions on blooms, seasonal and coastal distribution of the Florida red tide and progress in various research efforts. Emphasis is upon *Gymnodinium breve*.
Methods: None (research summary)
QA/QC: N/A
Contact: Tom Serota
Source Inst.: U. S. Fish and Wildlife Service, Fisheries Resources Office, 6300 Ocean Dr., Corpus Christi, Texas 78412 USA

Author: Sandgren, C. D.
Date: 1983
Title/Chap.: Survival strategies of chrysophycean flagellates: reproduction and the formation of resistant resting cysts
Book: *Survival strategies of the algae*
Editor: G. A. Fryxell
Pages: Pp. 23-48
Publisher: Cambridge University Press, Cambridge
Key words: chrysophytes, flagellates, survival strategy, reproduction, resting cyst, microalgae, resting stage, statospore, phytoplankton, life history
Summary: Many phytoplankton have resistant resting stages (cysts) as a necessary component of their life history strategy, enabling them to outlast unfavorable environmental conditions until recolonization of the plankton is possible. These strategies exist for both freshwater and marine phytoplankton. Freshwater chrysophytes known as golden algae are very seasonal species and use a siliceous resting cyst known as a statospore. The statospore is the primary subject of the review paper, which covers its development, surface morphology, and responses to factors influencing encystment, both in individual cells and populations. The author also refers early in the review to several general reference texts in phycology that address resting cysts in marine chrysophytes.
Methods: None *per se* (Review article)
QA/QC: N/A
Contact: Craig D. Sandgren
Source Inst.: Department of Biology, University of Texas at Arlington, Arlington, TX 76019

Author: Seliger, H. H., Tyler, M. A. and McKinley, K. R.
Date: 1979
Title/Ch.: Phytoplankton distributions and red tides resulting from frontal circulation patterns

Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 239-248
Publisher: Elsevier/North-Holland, Inc.
Key words: phytoplankton, distribution, red tide, frontal circulation, *Gymnodinium breve*, Florida, *Prorocentrum mariae lebouriae*, Chesapeake Bay
Summary: This paper extrapolates conditions existing for blooms of *Prorocentrum mariae lebouriae* in Chesapeake Bay with the west Florida red tides of *Gymnodinium breve* and that of another species in New England. Conditions promoting red tides include (1) downward movement of surface concentrations of red tide dinoflagellates resulting from wind and/or tidal influences, (2) transport to depth and toward shallow waters, (3) upwelling into the photic zones of shallow waters and (4) concentration into wind- or tide-driven convergences at the surface, producing dense surface patches. A specific scenario is included for each of the three locales.
Methods: N/A (Published hypothesis)
QA/QC: N/A
Contact: Howard H. Seliger
Source Inst.: McCollum-Pratt Institute and Department of Biology, The Johns Hopkins University, Baltimore, MD 21218 USA

Author: Shanley, E. and Vargo, G. A.
Date: 1990
Title/Ch.: Cellular composition, growth, photosynthesis, and respiration rates of *Gymnodinium breve* under varying light levels
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 831-836
Publisher: Elsevier
Key words: growth, photosynthesis, respiration, *Gymnodinium breve*, chlorophyll *a*, chlorophyll *c*, carotenoid
Summary: Laboratory cultures of Wilson's clone of the red tide dinoflagellate *Gymnodinium breve* were adapted to the full range of light available *in situ* in an attempt to measure and compare any variations in cellular composition, growth rates, respiration rates and rates of photosynthesis. Results indicated a proportional increase between photosynthesis and growth rates over a range of irradiance equal to about 2% to 16% of surface irradiance. The study's purpose was to clarify the low light response for *Gymnodinium breve* populations in offshore waters at depths of 20-30 m, where light levels can be as low as 2% of the mean daily incident irradiance and where bloom initiation is hypothesized. Findings reveal that offshore populations at such depths may indeed serve as seed populations for blooms.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."

Contact: Evanne Shanley
Source Inst.: Department of Marine Science, University of South Florida, 140 Seventh Avenue South, St. Petersburg, FL 33701 USA

Author: Shormann, D. E.
Date: 1992
Thesis: The effects of freshwater inflow and hydrography on the distribution of brown tide in south Texas bays
Pages: 111 pp.
Source: M. A. Thesis, Department of Marine Science, The University of Texas at Austin.
Key words: hydrography, brown tide, Texas, nitrate, Copano Bay, residence time, phosphate, ammonium, nitrite, silicate
Summary: The author created an equation to predict mean bay salinity and determine if Copano Bay mixing processes werre dominated by freshwater influx, tidal mixing or a combination thereof. A second equation was created to gauge residence time from freshwater inflow. Phytoplankton growth (including brown tide) did not appear to be either N- or P-limited. Mean chlorophyll concentrations were significantly correlated with with particulate carbon and nitrogen and thus from *in situ* phytoplankton production. A growth rate of the brown tide was only 0.14 day^{-1}. Copano Bay was eutrophic with respect to phosphorus and had a N/P ratio identical to fertilizer ratios used by local farmers. The mean residence and response times of Copano Bay were similar to Baffin Bay and about one order of magnitude greater than Nueces Bay. Such low water circulation could well aid persistence of the brown tide in those bays; notably, Nueces Bay is rarely affected by any algal bloom.
Methods: See "Methods" on pp. 18-25 and p. 94.
QA/QC: None *per se*; see "Methods."
Contact: Terry E. Whitledge
Source Inst.: The University of Texas Marine Science Institute, P. O. Box 1267, Port Aransas, TX 78373-1267

Author: Shumway, S. E.
Date: 1990
Title: A review of the effects of algal blooms on shellfish and aquaculture
Journal: *Journal of the World Aquaculture Society* 21(2):65-104
Key words: toxic algae, bloom, shellfish, aquaculture, dinoflagellates, *Gymnodinium breve*, *Ptychodiscus brevis*, *Gonyaulax monilata*, *Aureococcus anophagefferens*
Summary: This review paper comments on worldwide toxic algal blooms, presents the commercial management possibilities for coping with such blooms and suggests means of efficiently and successfully using marine resources in spite of the instability caused by blooms. Included are the two red tide dinoflagellates responsible for problem blooms along the Texas Gulf Coast and a brown tide chrysophyte similar to the organism that began blooming in the Laguna Madre in 1990.
Methods: N/A (Review paper)
QA/QC: N/A

Contact: Sandra E. Shumway
Source Inst.: Maine Department of Marine Resources and Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, Maine 04575 USA

Author: Siddall, S. E.
Date: 1987
Title: *Climatology of Long Island related to the "brown tide" phytoplankton blooms of 1985 and 1986*
Pages: 16 pp.
Publisher: Marine Sciences Research Center, SUNY, Stony Brook, NY
Key words: climatology, Long Island, brown tide, phytoplankton, bloom, meteorology, precipitation
Summary: Using long-term records to indicate prevailing trends over months or years for Long Island and short-term (daily) records of weather events for 1984-86 for five stations among East End bays, climatological/meterorological data were matched with brown tide cell counts in an effort to discover trends and suggest causative factors for the bloom during those two years. No significant anomalies in temperature, precipitation, wind or daily radiation could be associated with brown tide initiation or maintenance. Long Island experienced a moderate to severe drought when the first bloom occurred in 1985, but the report emphasizes that the mere existence of drought beforehand says nothing about true underlying causes for the bloom and cannot be considered statistically valid. A hypothesis of bloom formation and persistence can, however, be linked to precipitation and resulting terrestrial runoff or groundwater effects during an otherwise dry period.
Methods: N/A (Report)
QA/QC: N/A
Contact: Scott E. Siddall
Source Inst.: Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794-5000

Author: Sieburth, J. McN., Johnson, P. W. and Hargraves, P. E.
Date: 1988
Title: Ultrastructure and ecology of *Aureococcus anophagefferens* Gen. et sp. nov. (Chrysophyceae): the dominant picoplankter during a bloom in Narragansett Bay, Rhode Island, summer 1985
Journal: *J. Phycol.* 24:416-425
Key words: ultrastructure, ecology, *Aureococcus anophagefferens*, Chrysophyceae, picoplankton, bloom, Narragansett Bay, Rhode Island, *Synechococcus* Nägeli, *Calycomonas ovalis*
Summary: The unknown 2 um diameter chrysophyte herein described as the novel species *Aureococcus anophagefferens* first came to the authors attention with the cessation of feeding in filter feeders exposed to Narragansett Bay seawater and a density of 10^9 cell/L. Neither phase contrast nor epifluorescence microscopy could discriminate the chrysophyte from similar sized phytoplankton, though examination of thin sections with transmission electron microscopy was successful. About 300 attempts to culture the alga with twelve different culture media were unsuccessful.

Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: John McN. Sieburth
Source Inst.: Graduate School of Oceanography, University of Rhode Island Bay Campus, South Ferry Road, Narragansett, Rhode Island 02882-1197 USA

Author: Sieburth, J. McN. and Johnson, P. W.
Date: 1989
Title/Ch.: Picoplankton ultrastructure: a decade of preparation for the brown tide alga, *Aureococcus anophagefferens*
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 1-21
Publisher: Springer-Verlag
Key words: picoplankton, ultrastructure, brown tide, *Aureococcus anophagefferens*, transmission electron microscopy, TEM
Summary: In an effort to determine the trophic definition of pico- and nanoplankton, the authors developed a TEM process to examine thin sections of cells in the naturally occurring populations of uncultured seawater samples. With success depending on cells possessing unique ultrastructural characteristics, the authors, after a decade of such work on samples from Narragansett Bay, were in a unique position to examine samples of brown tide upon bloom occurrence there, beginning in 1985. Their timely sampling incriminated *Aureococcus anophagefferens* as the alga responsible for cessation of filter feeding during the bloom's peak. Re-examination of previous samples several years before the initial brown tide bloom revealed *A. anophagefferens* as a likely normal component of the picoplankton. Many such picoalgae probably remain unindentified.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: John McN. Sieburth
Source Inst.: Graduate School of Oceanography
University of Rhode Island, Narragansett, RI 92882-1197 USA

Author: Sievers, A. M.
Date: 1969
Title: Comparative toxicity of *Gonyaulax monilata* and *Gymnodinium breve* to annelids, crustaceans, molluscs and a fish
Journal: *Journal of Protozoology* 16(3):401-404
Key words: toxicity, *Gonyaulax monilata*, *Gymnodinium breve*, annelid, crustacean, mollusc, fish, dinoflagellate, mortality, toxin,
Summary: Several kinds of marine animals were exposed to concentrations of two dinoflagellate cultures from undiluted to 90% dilution over 48 hours in order to determine toxicity of the two toxins in terms of mortality. Fish were equally sensitive to both *Gonyaulax monilata* [preferably known as *Alexandrium*

monilata] and *Gymnodinium breve* toxins, crustaceans were resistant to both, and both annelids and molluscs were more sensitive to *G. monilata* toxin.

Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Anita M. Sievers
Source Inst.: Marine Laboratory, Texas A&M University, Galveston, TX 77550

Author: Smayda, T. J. and Fofonoff, P.
Date: 1989
Title/Ch.: An extraordinary, noxious brown-tide in Narragansett Bay. II. Inimical effects.
Book: *Red tides: biology, environmental science, and toxicology*. Proceedings of the First International Symposium on Red Tides held November 10-14, 1987, in Takamatsu, Kagawa Prefecture, Japan.
Editor: T. Okaichi, D. M. Anderson and T. Nemoto
Pages: 133-136
Publisher: Elsevier Science Publishing Company, Inc., New York
Key words: brown tide, Narragansett Bay, bloom, *Aureococcus anophagefferens* (appears as *A. anorexefferens*), zooplankton, *Mytilus edulis*, anchovy, kelp, benthic larvae, *Acartia tonsa*
Summary: The density of an *A. anophagefferens* bloom was strongly and negatively correlated (-0.91) with density of the predominant copepod *Acartia tonsa*; *A. tonsa* adult females fed the brown tide alga suffered lower feeding rates, egg production and body weight. Compared to 1984 and 1986, the 1985 bloom corresponded with a 60-fold lower mean cladoceran abundance. Natural mussel beds lost 30%-100% of their populations, apparently due to starvation, substantiated by cessation of filtering in laboratory-raised mussels at brown tide algal densities exceeded 500 x 10^6 cells/liter. Laminarian kelp died when the euphotic zone mussels to which they were attached also died and sank to deeper waters. *Aureococcus* abundance was also negatively correlated with benthic larval numbers ($r = -0.58$). Polychaete and bivalve larvae and bay anchovy eggs were all lower than normal (1.5x, 3.6x and 10x lower, resp.) as was zooplankton and benthic grazing.
Methods: None (Review paper)
QA/QC: N/A
Contact: Theodore J. Smayda
Source Inst.: Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881 USA

Author: Smayda, T. J. and Villareal, T. A.
Date: 1989
Title/Ch.: An extraordinary, noxious brown-tide in Narragansett Bay. I. The organism and its dynamics.
Book: *Red tides: biology, environmental science, and toxicology*. Proceedings of the First International Symposium on Red Tides held November 10-14, 1987, in Takamatsu, Kagawa Prefecture, Japan.
Editor: T. Okaichi, D. M. Anderson and T. Nemoto

Pages: 129-132
Publisher: Elsevier Science Publishing Company, Inc., New York
Key words: brown tide, Narragansett Bay, bloom, chrysophyte, *Aureococcus anophagefferens*
Summary: The *A. anophagefferens* bloom during May-September 1985 in Narragensett Bay produced densities as high as 1.2 x 10^9 cells/liter; mean abundance was strongly correlated (r = 0.98) with the observed salinity gradient, though authors suggest that salinity *per se* was not a causative factor. Neither was eutrophication, for strong inverse correlations appeared between mean abundance and "ammonium plus nitrate" and phosphate concentrations (-0.76 and -0.62, resp.). Diatoms, dinoflagellates, microflagellates and euglenids bloomed concurrently and extensively, with euglenids persisting through November once the brown tide bloom disappeared. Authors postulate that simultaneous brown tide blooms in Long Island and New Jersey indicate a mesoscale scenario associated with climatologic/hydrographic conditions. Spring increases in quantity or duration of light and concentrations of phagotrophic flagellates may be bloom catalysts.
Methods: None specified. See "Materials and Methods."
QA/QC: None. See "Materials and Methods."
Contact: Theodore J. Smayda
Source Inst.: Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881 USA

Author: Smayda, T. J. and Villareal, T. A.
Date: 1989
Title/Ch.: The 1985 'brown-tide' and the open phytoplankton niche in Narragansett Bay during summer
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 159-187
Publisher: Springer-Verlag
Key words: brown tide, phytoplankton, Narragansett Bay, chrysophyte, *Aureococcus anophagefferens*, bloom, niche
Summary: The authors call attention to the lack of information on the presence and abundance of other phytoplankton species before, during and after a bloom and suggest that such information may be crucial to a complete understanding of bloom dynamics. Smaller-scale but significant blooms of several diatom, dinoflagellate and other phytoflagellate species (a total of 14 other taxa) co-occurred with and/or followed the major *A. anophagefferens* bloom at different times and for various durations during May-October 1985 in Narragensett Bay. As a result, one may view blooms of these other taxa after the *A. anophagefferens* bloom ceased as exploitations of the niche previously dominated by *A. anophagefferens*. Future blooms should not be considered monospecific unless so proven.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Theodore J. Smayda

Source Inst.: Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881 USA

Author: Snider, R. (ed.)
Date: 1987
Title: *Red tide in Texas: an explanation of the phenomenon*
Pages: 4 pp.
Publisher: Marine Information Service, Texas A&M Sea Grant College Program
Key words: red tide, dinoflagellate, bloom, toxin, *Ptychodiscus brevis*, *Gonyaulax monilata*, Gulf of Mexico, fish kills, neurotoxic shellfish poisoning
Summary: This pamphlet summarizes the pertinent facts about the red tide organisms, *Ptychodiscus brevis* and *Gonyaulax monilata* [now known as *Gymnodinium breve* and *Alexandrium monilata*, resp.]; causes of sudden blooms; locations and times of bloom occurrence; red tide impacts on marine life, public health and the economy; myths about red tides; history and folklore; and control, prevention and prediction.
Methods: N/A (Public information bulletin)
QA/QC: N/A
Contact: Rhonda Snider
Source Inst.: Marine Information Service, Sea Grant College Program, Texas A&M University, College Station, TX 77843-4115

Author: Starr, T. J.
Date: 1958
Title: Notes on a toxin from *Gymnodinium breve*
Journal: *Texas Reports in Biology and Medicine* 16:500-507
Key words: toxin, *Gymnodinium breve*, bloom, algae, culture, mullet, *Lebistes reticulatus*, *Mugel cephalus*, exotoxin, endotoxin
Summary: This paper describes bioassay procedures for toxin from unialgal cultures of *Gymnodinium breve* as well as some properties of the crude toxin. Mullet and guppies were used for the toxin bioassay; toxicity increases with any agent that destroys *G. breve*. The organism's fragile nature frustrated attempts to concentrate the toxin by concentrating intact cells. The author cannot conclude that *G. breve* toxin is either a true exotoxin (produced or excreted from living cells) or endotoxin (introduced by cell lysis or autolysis).
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Theodore J. Starr
Source Inst.: The University of Texas Medical Branch, Department of Preventive Medicine and Public Health, Virus Research Laboratory, Galveston, Texas, USA

Author: Stehn, T.
Date: 1987
Title: Whooping cranes during the 1986-1987 winter
Pages: 45 pp.
Source: Aransas National Wildlife Refuge, U. S. Fish and Wildlife Service

Key words: whooping crane, habitat, red tide, algae, *Ptychodiscus brevis*, toxin, clam
Summary: In an excerpt from the unpublished report, the author reveals that the *Ptychodiscus brevis* [now *Gymnodinium breve*] red tide of 1986-87 in South Texas came very close to infiltrating whooping crane critical habitat in the Aransas National Wildlife Refuge in the fall of 1986. Because clams, swallowed whole, comprise a small part of a whooping crane's diet in fall and early winter, brevetoxin could possibly sicken or kill any cranes consuming contaminated clams. Because scaup and cormorants have been known to perish from exposure to brevetoxin in Florida, the potential threat to the small population of endangered whooping cranes calls for future monitoring.
Methods: None (unpublished report)
QA/QC: N/A
Contact: Tom Stehn, Refuge Biologist
Source Inst.: Aransas National Wildlife Refuge, US Fish and Wildlife Service, P. O. Box 100, Austwell, TX 77950 USA

Author: Steidinger, K. A.
Date: 1964
Title: *Gymnodinium breve* Davis
Source: Florida Board of Conservation Leaflet Series: Plankton, Vol. 1, No. 1 (2 pp.)
Key words: *Gymnodinium breve*, red tide, cyst, neurotoxin, bloom, dinoflagellate, Gulf of Mexico, salinity, temperature
Summary: This monograph provides a drawing, photomicrographs and a description of the red tide dinoflagellate *Gymnodinium breve*, plus comments on its distribution and ecology.
Methods: None (description)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K. A.
Date: 1975a
Title/Chap.: Basic factors influencing red tides
Book: *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 153-162
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: red tide, bloom, bloom initiation, dinoflagellate, sexual phase, benthic cyst, seed population, *Gymnodinium breve*, Florida
Summary: The author sets forth the three aspects common to all toxic red tides: (1) bloom initiation, defined as an increase in population size; (2) support, in terms of favorable levels of nutrients, growth factors, temperature and salinity; and (3) bloom maintenance and transport by meteorologic and hydrologic forces. At time of publication, dormant stages in the form of benthic cysts had not been

substantiated for *G. breve* (though true for many other species) nor had the concept of "seed populations" been proven, but such life cycle work was of high priority. The locality of bloom initiation was also considered critical, an example being the general location of *G. breve* blooms, at depths of 12-37 m 16-64 km offshore of southwest Florida, as a likely place to find dormant cysts. *G. breve* blooms, at least, were characterized from available data as gradual increases in motile cells, not sudden increases in cell division rates. Important transporting and concentrating mechanisms are listed as winds, currents and organism migration. Offshore sampling programs for adequate warning of blooms are highly recommended.

Methods: None (review)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. S. E., St. Petersburg, FL 33701 USA

Author: Steidinger, K. A.
Date: 1975b
Title: Implications of dinoflagellate life cycles on initiation of *Gymnodinium breve* red tides
Journal: *Environmental Letters* 9(2):129-139
Key words: dinoflagellate, life cycle, initiation, *Gymnodinium breve*, red tide, Florida, resting cyst, hypnozygote, seed population, sexuality
Summary: West Florida coastal waters 18-74 km offshore are the sites of red tide bloom initiation, usually in late summer or fall. If *G. breve* has a sexual cycle involving alternation of generations that includes a resting cyst stage (hypnozygote), then seed populations or seed "beds" could be located and mapped. The author reviews in detail advances in dinoflagellate life cycle work.
Methods: None (review)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. S. E., St. Petersburg, FL 33701 USA

Author: Steidinger, K. A.
Date: 1979
Title/Ch.: Collection, enumeration and identification of free-living marine dinoflagellates
Book: *Toxic Dinoflagellate Blooms*, Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, Oct. 31-Nov. 5, 1978
Editor: D. L. Taylor and H. H. Seliger
Pages: 435-442
Publisher: Elsevier/North-Holland, Inc.
Key words: dinoflagellate, Peridinales, theca, armored, unarmored, toxin, bloom, *Ptychodiscus brevis*
Summary: Water samples of dinoflagellates can be collected by numerous mechanical means depending on the species of interest, the study area and the researcher's purpose.

Formalin as both fixative and preservative is suggested for armored specimens, but unarmored species are difficult to fix and preserve. Enumeration methods are varied for both living and preserved cells. Plates of armored species may be distinguished optically, with stains, or by physical or chemical separation; cell size, shape, number and organelle placement are among other diagnostic features used to identify unarmored dinoflagellates. Cultures may confound identification due to culture-specific anomalous effects. Toxic species are thought to number less than 20, though many more produce blooms in estuaries and neritic waters. The name *Ptychodiscus brevis* [since renamed as *Gymnodinium breve*] is proposed for a toxic, bloom-producing species.

Methods: N/A (Review paper)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. S. E., St. Petersburg, FL 33701 USA

Author: Steidinger, K. A.
Date: 1983
Title/Ch.: A re-evaluation of toxic dinoflagellate biology and ecology
Book: *Progress in Phycological Research, Vol. 2*
Editor: Round and Chapman
Pages: 147-188
Publisher: Elsevier Science Publishers B. V.
Key words: toxic dinoflagellate, *Ptychodiscus brevis*, *Gymnodinium breve*, *Gonyaulax monilata*, Pyrrhophyta, neurotoxin, hemolytic agent, bloom, systematics, life history
Summary: This review summarizes toxic dinoflagellate research to 1983, commenting on systematics, life histories, toxins, organismal activity, environmental impacts and certain ecological aspects and suggesting avenues for future work. The two red tide dinoflagellates known to afflict the Texas Gulf Coast are included.
Methods: N/A (Review paper)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K. A. and Haddad, K.
Date: 1981
Title: Biologic and hydrographic aspects of red tides
Journal: *Bioscience* 31(11):814-819
Key words: red tide, bloom, dinoflagellate, life cycle, initiation, endotoxin, *Ptychodiscus brevis* [now *Gymnodinium breve*], sexual reproduction, satellite imagery
Summary: This article summarizes red tides in general, dinoflagellate biology, the sequential development of red tides and their occurrence in Florida, providing an excellent introduction to the state of knowledge and research on the factors concerning red tides in the eastern Gulf of Mexico as of 1981.

Methods: None (review)
QA/QC: N/A
Contact: K. A. Steidinger
Source Inst.: Bureau of Marine Research, Florida Department of Natural Resources, St. Petersburg, Fl 33701 USA

Author: Steidinger, K. A. and Ingle, R. M.
Date: 1972
Title: Observations on the 1971 summer red tide in Tampa Bay, Florida
Journal: *Environmental Letters* 3(4):271-278
Key words: red tide, Tampa Bay, Florida, dinoflagellate, *Gymnodinium breve*, bloom, cyst, estuaries, reefs, bivalves
Summary: Using information from a summer red tide on the west Florida coast that persisted for 3.5 months, the authors' observations suggest that (1) *Gymnodinium breve* is a neritic species hindered by low salinity barriers in estuaries, (2) dense cell concentrations are due more to physical factors than rapid cell division, (3) *G. breve* temporarily affects inshore and nearshore reef fisheries only, (4) commercial shellfish may be safely consumed 1-2 months after the end of a red tide event, (5) cyst populations in residence may become *G. breve* blooms, (6) pollution is not the catalyst for a Florida red tide, (7) *G. breve* blooms are probably annual occurrences and (8) monitoring programs can predict major Florida red tides.
Methods: None *per se*; methodological comments appear in "Results and Discussion."
QA/QC: N/A (Descriptive)
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K. A. and Joyce, E. A., Jr.
Date: 1973
Title: Educational Series No. 17: *Florida Red Tides*
Pages: 26 pp.
Publisher: State of Florida Department of Natural Resources, St. Petersburg
Key words: Florida, red tide, *Gymnodinium breve*
Summary: *Gymnodinium breve*, according to the authors, was very likely responsible for numerous recorded fish kills in Florida as early as 1844, but was not recognized and identified as the causative agent until 1948. Stating that red tides are natural occurrences, the authors conclude that there is a lack of means to control red tides with a concomitant warning that such means might harm the environment even if available.
Methods: N/A (Review paper)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K. A. and Vargo, G. A.

Date: 1988
Title/Ch.: 15. Marine dinoflagellate blooms: dynamics and impacts
Book: *Algae and Human Affairs*
Editor: C. A. Lembi and J. R. Waaland
Pages: 373-401
Publisher: Cambridge University Press, New York, NY
Key words: dinoflagellate, bloom, microalgae, Pyrrhophyta, red tide, paralytic shellfish poisoning, neurotoxic shellfish poisoning, diarrhetic shellfish poisoning, phytoplankton
Summary: A general review of the mechanisms and effects of marine dinoflagellate blooms, this paper recommends a multidisciplinary approach to identifying the physical-chemical forces of and biological responses to blooms. Hydrographic effects alter dinoflagellate behavior and location; variable light conditions can be accommodated by the organism's ability to modify photosynthetic pigment quality and quantity. Dinoflagellates can migrate and store nutrients; certain species produce toxins, and some bioluminesce. Reports of toxic blooms (red tides) are on the increase, including occurrences in areas previously unaffected; such blooms can restructure marine communities via selective mortality, threatening public health, commercial fishing and shellfish industries. Outside of negative economic impacts and health concerns, red tides, being natural occurrences, may not necessarily cause long-term negative ecological impacts.
Methods: N/A (Review paper)
QA/QC: N/A
Contact: Karen A. Steidinger
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K. A., and Williams, J.
Date: 1964
Title: *Gymnodinium breve* Davis
Source: Florida Board of Conservation Leaflet Series: Plankton, Vol. 1, No. 1A (Supplement, 2 pp.)
Key words: *Gymnodinium breve*, dinoflagellate, red tide, fish mortality, cyst formation, encystment, chromatophores, nucleus, Florida
Summary: The principal author published a monograph in the same leaflet series in early 1964 to which this is a supplement providing drawings, photomicrographs and documented observations of the red tide dinoflagellate *Gymnodinium breve*. The 63 cells collected and observed from a Florida outbreak causing fish mortality in mid-1964 differed from previous published observations, especially with respect to nucleus position, ventral concavity/dorsal convexity, the overhanging apical process and the length/breadth of the body. Also described was the process of encystment.
Methods: None (description)
QA/QC: N/A
Contact: Karen A. Steidinger

Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Steidinger, K., Babcock, C., Mahmoudi, B., Tomas, C. and Truby, E.
Date: 1989
Title/Ch.: Conservative taxonomic characters in toxic dinoflagellate species identification
Book: *Red tides: biology, environmental science, and toxicology*. Proceedings of the First International Symposium on Red Tides held November 10-14, 1987, in Takamatsu, Kagawa Prefecture, Japan.
Editor: T. Okaichi, D. M. Anderson and T. Nemoto
Pages: 285-288
Publisher: Elsevier Science Publishing Company, Inc., New York
Key words: numerical taxonomy, toxic, dinoflagellate, species identification, *Gymnodinium*, *Gyrodinium*, *Ptychodiscus*, *Prorocentrum*, optical pattern recognition
Summary: Proper identification is of concern to areas experiencing dinoflagellate blooms, especially those with no historical record of nor data on life history, biochemistry or growth of the bloom species. All such information is necessary for scientists to estimate negative impacts and establish monitoring programs. The taxonomy of toxic dinoflagellates is unfortunately still at the morphospecies level, and identification of conservative morphological characters/descriptors is still essential. This paper offers some apparently uniform, objective criteria to identify toxic dinoflagellate species.
Methods: See "Experimental."
QA/QC: None *per se*; see "Experimental."
Contact: Karen Steidinger
Source Inst.: Bureau of Marine Research, Florida Department of Natural Resources, St. Petersburg, Fl 33701 USA

Author: Stockwell, D. A., Buskey, E. J. and Whitledge, T. E.
Date: 1993
Title/Ch.: Studies on conditions conducive to the development and maintenance of a persistent "brown tide" in Laguna Madre, Texas
Book: *Toxic Phytoplankton Blooms in the Sea*
Editor: T. J. Smayda and Y. Shimizu
Pages: 693-698
Publisher: Elsevier Science Publishers B. V.
Key words: brown tide, Laguna Madre, Texas, Baffin Bay, bloom, chrysophyte, *Aureococcus anophagefferens*, *Pelagoccus subviridis*, dimethyl sulfide, microzooplankton
Summary: A 4-5 μm diameter organism similar to the Type III, aberrant group of chrysophytes appeared as a bloom from 6/90 and persisted for more than 18 months thereafter in the hypersaline waters of Baffin Bay and the Upper Laguna Madre of South Texas. Cell densities reached the order of 10^9 cells/l with chlorophyll *a* concentrations as much as 70 μg/l. The organism is capable of producing large amounts of dimethyl sulfide (DMS) and, while at maximum bloom in 7/90, was linked to a great reduction in microzooplankton grazing rates. The

authors suggest the coincidence of regional drought, local hypersalinity and the uncoupling of water column processes from the benthos led to the bloom.

Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Dean A. Stockwell
Source Inst.: Marine Science Institute, The University of Texas at Austin, P. O. Box 1267, Port Aransas, TX 78373-1267 USA

Author: Taylor, F. J. R.
Date: 1990
Title/Ch.: Red tides, brown tides and other harmful algal blooms: the view into the 1990's
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 527-533
Publisher: Elsevier
Key words: red tide, brown tide, algae, bloom, phytoplankton,
Summary: A concise overview of the proceedings of the Fourth International Conference on Toxic Marine Phytoplankton, this summary paper identifies what the author considered the major outstanding problems remaining (ca. 1990) in the study of toxic marine phytoplankton. Foremost for the purpose of this annotation are the elusive goal of accurate bloom prediction in most regions, the apparent increase in frequency of harmful blooms and the possibility of artificial dispersal (e.g., in the ballast water of ships) of bloom species from formerly restricted ranges of occurrence to distant sites.
Methods: N/A
QA/QC: N/A
Contact: F. J. R. Taylor
Source Inst.: Departments of Oceanography and Botany, Univeristy of British Columbia, Vancouver, B. C., Canada V6T 1W5

Author: Tester, P. A.
Date: 1992
Title/Chap.: Section VI: Phytoplankton distribution
Report: *Report on Investigation of 1990 Gulf of Mexico Bottlenose Dolphin Strandings*
Editor: L. J. Hansen
Pages: 44-47; Table 1; Figures 1-4; Appendix V
Publisher: National Oceanic and Atmospheric Administration, National Marine Fisheries Service
Key words: phytoplankton, *Gymnodinium breve*, dinoflagellate, Gulf of Mexico, red tide, bloom, brevetoxin, marine mammals, Galveston Bay, Mississippi delta
Summary: Of the 123 phytoplankton samples collected in the primary study area (between Galveston Bay and the Mississippi delta) in March of 1990, 80% contained *G. breve* cells. Upon detailed examination of the 70 samples taken in the upper half of the water column, 94% revealed the presence of *G. breve* cells, and 65% contained more than 50 cells/liter. Bloom concentrations are considered as at least

5000 cells/liter, so the cell counts from this study can be categorized as "normal background levels," but they were consistently greater than counts of samples from similar areas or from the primary study area later in the summer of 1990. (At that time, another toxic dinoflagellate, *Gonyaulax* [now *Alexandrium*] *monilata* was found near the Mississippi delta in elevated concentrations.)

Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Patricia A. Tester
Source Inst.: Southeast Fisheries Science Center (NOAA/NMFS), Beaufort Laboratory, Beaufort, NC 28516

Author: Tester, P. A. and Fowler, P. K.
Date: 1990
Title/Ch.: Brevetoxin contamination of *Mercenaria mercenaria* and *Crassostrea virginica*: a management issue
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 499-503
Publisher: Elsevier
Key words: brevetoxin, *Mercenaria mercenaria*, *Crassostrea virginica*, red tide, *Ptychodiscus brevis*, bloom, North Carolina, shellfish, clam
Summary: The authors examine factors affecting the toxicity of *Mercenaria mercenaria* and *Crassostrea virginica* during and after a *P. brevis* [aka *Gymnodinium breve*] bloom in the field and suggest changes in the American Public Health Association guidelines concerning what is an acceptable amount of neurotoxic shellfish poisoning (NSP) toxin in shellfish harvested for human consumption. They also note that *P. brevis* requires salinities in excess of 24 ppt.
Methods: See “Methods.”
QA/QC: None *per se*; see “Methods.”
Contact: Patricia A. Tester
Source Inst.: National Marine Fisheries Service, NOAA, Beaufort, NC 28516 USA

Author: Tester, P. A., Geesey, M. A. and Vukovich, F. M.
Date: 1993
Title/Ch.: *Gymnodinium breve* and global warming: what are the possibilities?
Book: *Toxic Phytoplankton Blooms in the Sea*, Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton
Editor: T. J. Smayda and Y. Shimizu
Pages: 67-72
Publisher: Elsevier Science Publishers B. V.
Key words: *Gymnodinium breve*, global warming, Gulf Stream, North Carolina, red tide, bloom, South Atlantic Bight, Florida Current, Gulf of Mexico
Summary: An unusual red tide bloom in North Carolina in 1987-88 may have resulted from transport of a seed population from the west Florida shelf into the South Atlantic Bight (SAB) by the Florida Current-Gulf Stream System. Continuous transport of

this kind has been implicated by water samples collected by NOAA vessels in the northern Gulf of Mexico (GOM) and the SAB, for *G. breve* appears to be continously distributed from the GOM throughout the SAB regardless of season. Twelve incursions of the warmer Gulf Stream into the shelf waters of the SAB were associated with detectable levels of *G. breve* cells during the winter of 1990-91. When SAB shelf water temperatures increase in summer, Gulf Stream incursions are more difficult to detect and the growth of *G. breve* populations is better supported. Variations in the transport and distribution of *G. breve* may be useful for assessing global climate change and its effects on the water temperature and circulation patterns between the GOM and the SAB. The authors add that one liter was the minimum volume necessary for detection of *G. breve* cells in the SAB, at least ten times the quantity typically examined with the standard Utermöhl settling chamber methodology.

Methods: See "Introduction."
QA/QC: None *per se*; see "Introduction."
Contact: Patricia A. Tester
Source Inst.: National Marine Fisheries Service--NOAA, Southeast Fisheries Science Center, Beaufort Laboratory, Beaufort, NC 28516 USA

Author: Tester, P. A., Stumpf, R. P., Vukovich, F. M., Fowler, P. K., and Turner, J. T.
Date: 1991
Title: An expatriate red tide bloom: transport, distribution, and persistence
Journal: *Limnol. Oceanogr.* 36(5):1053-1061
Key words: red tide, bloom, transport, distribution, dinoflagellate, *Gymnodinium breve*, North Carolina, Gulf of Mexico Loop Current, Florida Current, Gulf Stream
Summary: A *Gymnodinium breve* bloom occurred in North Carolina nearshore waters in November of 1987, the first to occur north of Florida due to *G. breve*. The authors propose that the Gulf Stream Loop Current entrained a portion of a *G. breve* bloom in progress off the southwest Florida coast, then transported it, via the Florida Current-Gulf Stream system, around the Florida peninsula and north over 800 km and 22-54 days to North Carolina. Thirty days after the southwest Florida bloom, satellite sea-surface temperature images confirmed movement of a parcel of Gulf Stream water onto the shelf between Cape Hatteras and Cape Lookout and its residence there for >19 days, a likely source of the *G. breve* cells. Once inshore, windspeed and direction largely controlled its distribution.
Methods: None *per se* (note).
QA/QC: N/A
Contact: Patricia A. Tester
Source Inst.: National Marine Fisheries Service, NOAA, Southeast Fisheries Center, Beaufort Laboratory, Beaufort, NC 28516 USA

Author: Texas Parks and Wildlife Department
Date: 1986
Title: Commission Agenda Item (Briefing Session): *Red Tide*
Pages: 3 pp.

Key words: red tide, bloom, algae, dinoflagellate, *Ptychodiscus brevis*, neurotoxin, Gulf of Mexico, aerial surveillance, fish mortality, aerosol toxin

Summary: This report highlights the impact on marine fishes by the red tide dinoflagellate *Ptychodiscus brevis* during the extensive bloom that began during Labor Day weekend of 1986. The red tide moved steadily southward from the first fish kill noted offshore of Galveston, Texas, and by November had reached Mexican beaches at Tampico and the Bay of Campeche. Causative factors were unclear, for the organism's preference for salinities greater than 28 ppt and temperatures exceeding 60°F is commonly fulfilled in late summer along Texas shores, yet without blooms. Total fish mortality was estimated at more than 7.5 million individuals, mainly menhaden and mullet, but including pinfish, red drum, spotted seatrout, black drum, southern flounder and Atlantic croaker. Oyster harvesting was prohibited, and numerous beaches were closed due to dead fish and aerosol toxin.

Methods: N/A (Briefing report)

QA/QC: N/A

Contact: Larry McEachron

Source Inst.: Texas Parks & Wildlife Department, Coastal Fisheries Division, 702 Navigation Circle, Rockport, TX 78382

Author: Tracey, G. A.

Date: 1988

Title: Feeding reduction, reproductive failure, and mortality in *Mytilus edulis* during the 1985 'brown tide' in Narragansett Bay, Rhode Island

Journal: *Mar. Ecol. Prog. Ser.* 50:73-81

Key words: feeding, reproduction, mortality, *Mytilus edulis*, brown tide, Narragansett Bay, Rhode Island, bloom, chrysophyte, *Mercenaria mercenaria*,

Summary: The blue mussel, *Mytilus edulis*, suffered reduced clearance rates, reproductive failure and high mortality in response to a dense, novel brown tide bloom (10^6 cells/ml) in Narragansett Bay, RI in the summer of 1985. Using natural particulates from Narragansett Bay in the clearance rate experiments with the blue mussel, the authors replicated the experiment and saw similar inhibition in the hard clam, *Mercenaria mercenaria*. Deleterious experimental effects appeared when particles exceeded 5.0×10^5 particles/ml, whereas bay concentrations ranged from 9×10^5 to 15×10^5 particles/ml. Blue mussel mortality in the bay varied from 30-100% with concomitant reproductive failure, neither of which could be attributed to temperature, salinity or dissolved oxygen concentrations.

Methods: See "Materials and Methods."

QA/QC: None *per se*; see "Materials and Methods."

Contact: Gregory A. Tracey

Source Inst.: Science Applications International Corporation, Marine Services Branch, US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, Rhode Island 92882 USA

Author: Tracey, G. A., Johnson, P. W., Steele, R. W., Hargraves, P. E. and Sieburth, J. McN.

Date: 1988
Title: A shift in photosynthetic picoplankton composition and its effect on bivalve mollusc nutrition: the 1985 "brown tide" in Narragansett Bay, Rhode Island
Journal: *Journal of Shellfish Research* 7(4):671-675
Key words: photosynthesis, picoplankton, bivalve, mollusc, nutrition, brown tide, Narragansett Bay, *Synechococcus*, bloom, *Mytilus edulis*
Summary: Upon analysis by epifluorescence and transmission electron microscopy, water samples from the brown tide bloom of 1985 in Narragansett Bay, Rhode Island, revealed 10-fold greater concentrations of bacteria (10^7 cells/ml) during the peak of the bloom. A 1.5-2.0 µm chrysophyte composed 95% of the total phytoplankton by abundance at about 10^6 cells/ml. The photosynthetic cyanobacterium *Synechococcus* was 10-fold lower in abundance than the usual 5 x 105 cells/ml. The brown tide organism reduced feeding in the mussel *Mytilus edulis*, but clearance rates were optimal for comparable densities of a similar-sized strain of *Synechococcus*. The mussel's nutrition and growth may thus be affected by the species composition of the picoplankton.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Gregory A. Tracey
Source Inst.: Science Applications International Corporation, Marine Services Branch, c/o U. S. Environmental Protection Agency, South Ferry Rd., Narragansett, RI 02882 USA

Author: Tracey, G. A., Steele, R. L., Gatzke, J., Phelps, D. K., Nuzzi, R., Waters, M. and Anderson, D. M.
Date: 1989
Title/Ch.: Testing and application of biomonitoring methods for assessing environmental effects of noxious algal blooms
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 557-574
Publisher: Springer-Verlag
Key words: biomonitoring, bloom, *Aureococcus anophagefferens*, Peconic Bay, Long Island, New York, brown tide, mussel, *Mytilus edulus*, *Minutocellus polymorphus*
Summary: The authors evaluated biomonitoring methods in waters with a history of noxious algal blooms, in this case the Peconic Bays system of Long Island, New York, where a mild bloom occurred in June-September, 1988. Objectives included (1) the effect on bivalve nutrition by the characteristics of algae and other suspended particulates and (2) the effect on bivalve growth and physiology by environmental conditions in different bay locations. Reduced feeding and slower growth for mussels in Peconic Bay were attributed in the main to the deleterious influence of *Aureococcus anophagefferens*, with possible added negative effects due to the nanoplanktonic diatom, *Minutocellus polymorphus*.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."

Contact: Gregory A. Tracey
Source Inst.: Science Applications International Corporation, c/o U. S. Environmental Protection Agency, Environmental Research Laboratory-Narragansett, Narragansett, Rhode Island 02882 USA

Author: Tracey, G., Steele, R. and Wright, L.
Date: 1990
Title/Ch.: Variable toxicity of the brown tide organism, *Aureococcus anophagefferens*, in relation to environmental conditions for growth
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 128-131
Publisher: Elsevier
Key words: toxicity, brown tide, *Aureococcus anophagefferens*, growth, blue mussel, *Mytilus edulis*
Summary: Varying light, temperature and nutrient regimes in *A. anophagefferens* cultures, then checking the feeding response of *M. edulis* on the brown tide organism, the authors found that *Aureococcus* toxicity in late-exponential phase growth was lower in low light as opposed to high light, greater at higher versus lower temperatures and increased in high rather than low nutrient concentrations. The same kinds of conditions may affect the alga's toxicity *in situ*.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Gregory Tracey
Source Inst.: Science Applications International Corporation, c/o U. S. Environmental Protection Agency, Narragansett Bay, Rhode Island 02882 USA

Author: Trainer, V. L. and Baden, D. G.
Date: 1990
Title/Ch.: Enzyme immunoassay of brevetoxins
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 430-435
Publisher: Elsevier
Key words: enzyme, immunoassay, brevetoxin, *Ptychodiscus brevis* (aka *Gymnodinium breve*), red tide, dinoflagellate, ELISA, enzyme-linked immunosorbent assay, Florida
Summary: At the time of the study, the only assays available to detect the presence of brevetoxins in seafood were impractical for field use. The authors analyzed the usefulness of two different brevetoxin-enzyme conjugates via enzyme-linked immunosorbent assays (ELISAs), the results of which are visual and could possibly be read in the field. The two toxin-enzyme conjugates can be standardized to test for brevetoxin in unknown field samples, though their stability must first be assessed and the overall anti-brevetoxin ELISA optimized.
Methods: See "Methods."

QA/QC: None *per se*; see "Methods."
Contact: Vera L. Trainer
Source Inst.: Department of Biochemistry and Molecular Biology, University of Miami, Miami, FL 33149 USA

Author: Trebatoski, B.
Date: 1988
Title: *Observations on the 1986-1987 Texas Red Tide (Ptychodiscus brevis)*, Report 88-02
Pages: 48 pp.
Publisher: Texas Water Commission
Key words: red tide, *Ptychodiscus brevis*, Texas, dinoflagellate, Gulf of Mexico
Summary: This study documents the spread and impact of a bloom of the toxic dinoflagellate *Ptychodiscus brevis* [now *Gymnodinium breve*] that affected Gulf of Mexico coastal waters from Galveston to Port Isabel, Texas, and on into Mexico from August 1986 through January 1987. Plankton and water chemistry samples along with boat and aerial surveys were the prinicipal means of judging the effects of the red tide, which produced massive fish mortality, irritating aerosols and contamination of shellfish beds and discouraged tourism and seafood consumption. The resulting large-scale bioperturbation actually may have been a positive influence on the environment.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Bob Trebatoski
Source Inst.: Texas Water Commission, P. O. Box 13087, Austin, TX 78711 USA

Author: Vargo, G. A., Carder, K. L., Gregg, W., Shanley, E., Neil, C., Steidinger, K. A. and Haddad, K. D.
Date: 1987
Title: The potential contribution of primary production by red tides to the west Florida shelf ecosystem
Journal: *Limnol. Oceanogr.* 32(3):762-767
Key words: primary production, red tide, west Florida shelf, dinoflagellate, bloom, *Ptychodiscus brevis*, CZCS imagery
Summary: Field and laboratory estimations of and some data for daily and monthly production rates and theoretical annual carbon input for the red tide dinoflagellate *Ptychodiscus brevis* [now *Gymnodinium breve*] revealed that bloom rates were 2-5 times greater than published values or non-bloom rates. Annually, red tide blooms of *P. brevis* could be responsible for a significant proportion of annual production in the water column of the west Florida shelf.
Methods: None *per se*; see text. (Research note)
QA/QC: N/A
Contact: Gabriel A. Vargo
Source Inst.: Department of Marine Science, University of South Florida, 140 7th Ave. South, St. Petersburg, FL 33701 USA

Author: Vargo, G. A. and Howard-Shamblott, D.
Date: 1990
Title/Ch.: Phosphorus dynamics in *Ptychodiscus brevis*: cell phosphorus, uptake and growth requirements
Book: *Toxic Marine Phytoplankton*, Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton
Editor: E. Granéli, B. Sundström, L. Edler and D. M. Anderson
Pages: 324-329
Publisher: Elsevier
Key words: phosphorus, *Ptychodiscus brevis*, bloom, West Florida Shelf, red tide, dinoflagellate, Gulf of Mexico
Summary: This study concerns nutrient-growth interactions for *P. brevis* (renamed *Gymnodinium breve*) and phosphorus. Blooms of this species are initiated 18 to 74 km offshore of Florida's west coast in highly oligotrophic waters. Bloom persistence should be related to the ability to efficiently extract, stock and use nutrients for growth and maintenance, but *P. brevis* does not possess a high phosphorus storage capacity, though it can apparently store phosphorus in two different cellular storage pools, the significance to growth of which has yet to be determined. Phosphorus uptake rates for *P. brevis*, however, are more than an order of magnitude above those of other dinoflagellates. The uptake rates, half-saturation constant for growth and long generation times of *P. brevis* enable it to bloom in the presence of relatively excess phosphorus and maintain populations in offshore waters with low phosphorus concentrations.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Gabriel A. Vargo
Source Inst.: Department of Marine Science, University of South Florida, 140 Seventh Avenue South, St. Petersburg, Florida 33701 USA

Author: Vieira, M. E. C. and Chant, R.
Date: 1993
Title: On the contribution of subtidal volume fluxes to algal blooms in Long Island estuaries
Journal: *Estuarine, Coastal and Shelf Science* 36:15-29
Key words: algae, bloom, Long Island, estuary, subtidal volume flux, picoplankton, *Aureococcus anophagefferens*, sea level fluctuation, flushing time, wind stress
Summary: Tidal data taken from 1980-88 for oceanic locations near Nantucket, MA, Montauk, NY and Atlantic City, NJ and for four Long Island estuaries revealed that sea level fluctuations due to subtidal frequencies were greater than tidal frequencies and were seasonal in their magnitude. When the spring1985 brown tide bloom (*Aureococcus anophagefferens*) occurred along with a drought in Long Island bays, subtidal variance was at an absolute minimum, subtidal flushing times were correspondingly slow and freshwater influx was reduced. As a result, inorganic nutrients may have been available for longer than usual, supporting the expansive bloom of *A. anophagefferens*.
Methods: See "Data Base."

QA/QC: None *per se*; see “Data Base” and “Analysis and Results.”
Contact: Mario E. C. Vieiraá
Source Inst.: Oceanography Department, US Naval Academy, Annapolis, MD 21402-5026 USA

Author: Walker, L. M.
Date: 1982
Title: Evidence for a sexual cycle in the Florida red tide dinoflagellate, *Ptychodiscus brevis* (= *Gymnodinium breve*)
Journal: Transactions of the American Microscopical Society 101(3):287-293
Key words: sexual cycle, Florida, red tide, dinoflagellate, *Gymnodinium breve*, gametes, planozygotes, cyst
Summary: Non-clonal stock cultures provided evidence of isogamous, haploid gametes and diploid planozygotes in the sexual cycle of *Gymnodinium breve*. Though no hypnozygotes were ever positively identified in the cultures, apparent hypnozygotic cysts may have formed in one preliminary experiment and were also recovered from field samples.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Linda M. Walker
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Avenue South East, St. Petersburg, Florida 33701-5095 USA

Author: Walker, L. M., and Steidinger, K. A.
Date: 1979
Title: Sexual reproduction in the toxic dinoflagellate *Gonyaulax monilata*
Journal: Journal of Phycology 15:312-315
Key words: reproduction, dinoflagellate, *Gonyaulax monilata*, sexual cycle, isogametes, planozygote, hypnozygote, archeopyle, red tide, seed bed
Summary: The authors observed the induction of the sexual cycle of *Gonyaulax* [now *Alexandrium*] *monilata* in nonclonal laboratory cultures within one week after inoculating asexual cells into nitrogen-deficient media. Asexual cells can produce two armored, motile, isogamous gametes. Two gametes fuse to form a large double-flagellated planozygote that encysts as a hypnozygote with a three-layered cyst wall 1-3 weeks later. The cell that emerges from the cyst divides twice to form a four-celled chain within three days. The authors report that cysts of *G. monilata* were found in Tampa Bay sediments, were excysted and produced chains of cells identical to those studied in the nonclonal laboratory cultures.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: Linda M. Walker
Source Inst.: Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Avenue S.E., St. Petersburg, FL 33701

Author: Wall, D.
Date: 1975

Title/Chap.: Taxonomy and cysts of red-tide dinoflagellates
Book: *Proceedings of The First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 249-255
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: taxonomy, cyst, red tide, dinoflagellate, life cycle, theca, *Gonyaulax*, species-complex
Summary: Many dinoflagellate species, both estuarine and neritic, produce a cyst at some part of their life cycle. Cysts are composed of a variety of materials, can provide taxonomic information and have indicated that the Genus *Gonyaulax* is genetically heterogeneous with seven species complexes. The *G. tamarensis* complex includes red-tide species such as *Gonyaulax* [now *Alexandrium*] *monilata* and possesses a distinctive thecal morphotype common to all species in the complex and some others. Taxonomic revision is needed for the Genus *Gonyaulax* and others, and cyst cycles should be employed to identify species complexes.
Methods: None (review)
QA/QC: N/A
Contact: David Wall
Source Inst.: Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA

Author: Ward, J. E. and Targett, N. M.
Date: 1989
Title/Ch.: Are metabolites from the brown tide alga, *Aureococcus anophagefferens*, deleterious to mussel feeding behavior?
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 543-556
Publisher: Springer-Verlag
Key words: metabolites, brown tide, *Aureococcus anophagefferens*, mussel, bloom, *Isochrysis galbana*, *Heterosigma akashiwo*, *Dunaliella tertiolecta*
Summary: Given the adverse effects of *A. anophagefferens* on bivalves, the lack of phytoplankton diversity during the brown tide blooms and the high densities of the brown tide alga, the authors hypothesized a metabolite detrimental to bivalve feeding behavior. They found, however, no evidence of a negative effect by *A. anophagefferens* on mussel filtration rates, particle selection or valve movements, even at densities of 10^5-10^6 cells/ml. Their findings do not rule out toxic effects of metabolite exposure for days or weeks, rapidly degrading metabolites or harmful epicellular constituents.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: J. Evan Ward
Source Inst.: University of Delaware, College of Marine Studies, Lewes, DE 19958 USA

Author: Wardle, W. J., Ray, S. M. and Aldrich, A. S.

Date: 1975
Title/Ch.: Mortality of marine organisms associated with offshore summer blooms of the toxic dinoflagellate *Gonyaulax monilata* Howell at Galveston, Texas
Book: *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 257-263
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: mortality, bloom, dinoflagellate, *Gonyaulax monilata*, Galveston, Texas, snail, hermit crab, brittle star, red tide
Summary: The authors document two red tides of the toxic dinoflagellate *Gonyaulax monilata* [preferred name *Alexandrium monilata*] that occurred in waters near Galveston, Texas in the summers of 1971 and 1972, with recorded maximum cell densities of 1.2×10^6 cells/L and 1.88×10^6 cells/L, respectively. Twenty-nine species of cnidarians, annelids, molluscs, crustaceans, echinoderms and fishes, all sedentary or slow-moving, were represented among the organisms that perished from the toxin. Monitoring in the summers of 1973 and 1974 did not detect the presence of *G. monilata*, perhaps due to lower salinities (<32 ppt) and temperatures (<29°C) relative to the preceding two summers in the Galveston Bay drainage area.
Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: William J. Wardle
Source Inst.: Department of Marine Sciences, Texas A & M University, Galveston, TX 77550

Author: Watson, R. L., and Behrens, E. W.
Date: 1970
Title: Nearshore surface currents, southeastern Texas Gulf Coast
Journal: *Contributions in Marine Science* 15:133-143
Key words: surface circulation, drift bottles, Texas, Gulf of Mexico, Padre Island, convergence, cold front, trade winds, longshore currents, sediment transport
Summary: Numerous unweighted drift bottles were released monthly at points corresponding to water depths of three, six and eight fathoms along six traverses perpendicular to the shoreline between Port Aransas and Port Isabel, Texas from October 1966 to December 1967. Drift bottle movements indicated that the nearshore circulation of eight fathoms and less was largely controlled by the local prevailing winds with some exceptions in the spring. The convergence of the net annual littoral drift occurs on the central Texas coast, but the nodal point varies between the estimate from wind data and that from sediment distribution.
Methods: See "Procedure."
QA/QC: N/A (Physical oceanography)
Contact: E. William Behrens
Source Inst.: Marine Science Institute, The University of Texas, P. O. Box 1267, Port Aransas, TX 78373-1267 USA

Author: Whitledge, T. E.

Date: 1993
Title/Ch.: The nutrient and hydrographic conditions prevailing in Laguna Madre, Texas before and during a brown tide bloom
Book: *Toxic Phytoplankton Blooms in the Sea*
Editor: T. J. Smayda and Y. Shimizu
Pages: 711-716
Publisher: Elsevier Science Publishers B. V.
Key words: nutrients, Laguna Madre, Texas, brown tide, bloom, pigment, chrysophyte, Baffin Bay, dissolved inorganic nitrogen, ammonium
Summary: An unidentified aberrant chrysophyte bloomed widely for more than 18 months in the hypersaline Laguna Madre. The bloom followed dissolved inorganic nitrogen (DIN) concentrations of almost 20 µmol/l, especially in Baffin Bay, with ammonium composing 60-95% of the DIN. Baffin Bay, subject to annual salinity variations of as much as 65 ppt, also had the greatest salinity of the north to south gradient in the Laguna Madre, ranging from 40-60 ppt during the bloom.
Methods: See "Methods."
QA/QC: None *per se*; see "Methods."
Contact: Terry E. Whitledge
Source Inst.: Marine Science Institute, The Univerity of Texas at Austin, P. O. Box 1267, Port Aransas, TX 78373 USA

Author: Whitledge, T. E. and Pulich, W. M., Jr.
Date: 1991
Title: *Report of Brown Tide Symposium and Workshop*, 15-16 July 1991
Pages: 44 pp.
Publisher: University of Texas Marine Science Institute Technical Report TR/91-002
Key words: brown tide, bloom, seagrass, grazing, nutrients, hydrography, light, benthos, zooplankton, ichthyoplankton
Summary: This report consolidates the abstracts of all presentations given at the symposium/workshop and summarizes the results in the forms of (1) comparisons/contrasts between characteristics of geographically isolated occurrences of brown tide and (2) recommendations for future research.
Methods: N/A
QA/QC: N/A
Contact: Terry E. Whitledge
Source Inst.: Marine Science Institute, The University of Texas, P. O. Box 1267, Port Aransas, TX 78373 USA

Author: Williams, J., and Ingle, R. M.
Date: 1972
Title: Ecological Notes on *Gonyaulax monilata* (Dinophyceae) Blooms Along the West Coast of Florida
Source: Florida Department of Natural Resources Leaflet Series: Phytoplankton, Part 1 (Dinoflagellates), No. 5
Key words: *Gonyaulax monilata*, dinoflagellate, Florida, fish kill, bloom, *Gymnodinium breve*

Summary: The first bloom of the toxic dinoflagellate *Gonyaulax monilata* [now *Alexandrium monilata*] off the west coast of Florida is the subject of this note. The organism caused fish kills and, also for the first time anywhere, was detected blooming in offshore waters, not just estuarine or nearshore environments, in the late summer of 1966. A *Gymnodinium breve* bloom followed the *G. monilata* bloom in October.
Methods: None
QA/QC: N/A (Report)
Contact: Jean Williams
Source Inst.: Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, FL 33701 USA

Author: Wilson, W. B.
Date: 1965
Title: The suitability of sea-water for the survival and growth of *Gymnodinium breve* Davis; and some effects of phosphorus and nitrogen on its growth
Journal: *Florida Board of Conservation Professional Papers Series* No. 7:1-42
Key words: *Gymnodinium breve*, dinoflagellate, bloom, toxin, growth, phosphorus, nitrogen, chelator, iron, glycerophosphate
Summary: The toxic marine dinoflagellate *G. breve* was used as a bioassay organism to test the suitability of various seawater samples from the West Florida coast and Galveston Island to support its survival and growth. Of the few seawater samples that were suitable, experiments determined which substances used for *G. breve* culture media would promote growth in those samples. Survival and growth in most samples were improved by addition of the chelator EDTA or a combination of EDTA and iron. EDTA, iron and an inorganic mixture with nitrogen and phosphorus improved growth more than any other additive combination in 1964 seawater samples, but inorganic nutrients alone were not generally effective. High *G. breve* concentrations, however, were not seen in response to most additives. Higher phosphorus concentrations in artificial media supported relatively greater cell densities, but populations with less than 6.0 µg P/liter did not continue to grow. Glycerophosphate as the sole phosphorus source was acceptable; nitrate-nitrite was not required, but some form of organic nitrogen was essential.
Methods: See "Sample Procedure and Assay Methods."
QA/QC: None *per se*; see "Sample Procedure and Assay Methods."
Contact: William B. Wilson
Source Inst.: Texas A & M Marine Laboratory, Galveston, Texas, USA

Author: Wilson, W. B.
Date: 1967
Title: Forms of the dinoflagellate *Gymnodinium breve* Davis in cultures
Journal: *Contributions in Marine Science* 12:120-134
Key words: dinoflagellate, *Gymnodinium breve*, culture, morphology, encystment stage, cyst, cell division, reproduction, bloom, Gulf of Mexico
Summary: Cultured cells of the marine dinoflagellate *Gymnodinium breve* are described and discussed with respect to the most common encystment stage, general features of

cell division, other possible reproductive stages and forms resulting from varied physical factors and reproductive stages. The author includes numerous photographs and some line drawings.

Methods: None *per se* (descriptive paper).
QA/QC: N/A
Contact: William B. Wilson
Source Inst.: Marine Laboratory, Texas A & M University, Galveston, Texas, USA

Author: Wilson, W. B. and Ray, S. M.
Date: 1956
Title: The occurrence of *Gymnodinium brevis* in the western Gulf of Mexico
Journal: *Ecology* 87(2):388
Key words: *Gymnodinium brevis*, Gulf of Mexico, fish mortality, Port Isabel, Texas, Rio Grande River
Summary: September of 1955 saw a widely documented fish kill apparently due to the red tide dinoflagellate *Gymnodinium brevis* [now preferably known as *Gymnodinium breve*] that littered the Gulf coast from a point 17 miles north of Port Isabel to the mouth of the Rio Grande in Texas as well as a 120-mile stretch in the Mexican state of Tamaulipas. Highest reported densities were found 36 miles south of the Rio Grande River mouth at no less than 22,000 cells/ml.
Methods: N/A (Report)
QA/QC: N/A
Contact: W. B. Wilson
Source Inst.: Gulf Fishery Investigations, U. S. Fish and Wildlife Service, Galveston, TX, USA

Author: Wilson, W. B., Ray, S. M., and Aldrich, D. V.
Date: 1975
Title/Chap.: *Gymnodinium breve*: population growth and development of toxicity in cultures
Book: *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 127-141
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: *Gymnodinium breve*, growth, toxicity, culture, dinoflagellate, toxicity assay, mosquito fish, *Gambusia affinis*
Summary: Eight 12-liter cultures of *Gymnodinium breve* were maintained for five months in this study of population growth and toxicity. Each culture received an estimated inoculation of 50,000-60,000 cells per liter, but population levels inexplicably diminished rapidly to 3000-9000 cells per liter shortly after inoculation. All populations, however, reached at least 5 million cells per liter by five weeks (a calculated population growth rate of 0.3/day). Populations varied thereafter, ranging from a half million to 24 million per liter after five months. Cultures were considered replicates, but no cause was apparent for the density variance. Toxicity (determined with the mosquito fish, *Gambusia affinis*) and bacterial population levels varied directly with *G. breve* cell concentration; the ratio of large to small

cells was greater in populations with increasing as opposed to decreasing populations.

Methods: See "Materials and Methods."
QA/QC: None *per se*; see "Materials and Methods."
Contact: William B. Wilson
Source Inst.: Department of Marine Science, Texas A & M University, Galveston, Texas, USA

Author: Wyatt, T.
Date: 1975
Title/Chap.: The limitations of physical models for red tides
Book: *Proceedings of the First International Conference on Toxic Dinoflagellate Blooms*
Editor: V. R. LoCicero
Pages: 81-93
Publisher: The Massachusetts Science and Technology Foundation, Wakefield, MA
Key words: physical model, red tide, circulation pattern, vertical stability, advection, diffusion, plankton distibution
Summary: Circulation patterns seen in both shallow water and deep water above a pycnocline and processes that increase vertical stability in the water column are the two major oceanographic processes commonly used to address the influence of the physical environment on red tide concentrations. The two may not be distinct and may occur concurrently, but making such a distinction may aid understanding of small-scale oceanographic features that influence plankton population distribution. The paper reviews the two processes (advective and diffusive) regarding their usefulness in understanding the mechnisms affecting red tides apart from those that are ecological.
Methods: None (review)
QA/QC: N/A
Contact: T. Wyatt
Source Inst.: Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, NZ

Author: Yentsch, C. S., Phinney, D. A. and Shapiro, L. P.
Date: 1989
Title/Ch.: Absorption and fluorescent characteristics of the brown tide chrysophyte: its role on light reduction in coastal marine environments
Book: *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*, Coastal and Estuarine Studies 35
Editor: E. M. Cosper, V. M. Bricelj and E. J. Carpenter
Pages: 77-83
Publisher: Springer-Verlag
Key words: brown tide, chrysophyte, phytoplankton, bloom, absorption spectra, fluorescence spectra, *Skeletonema* sp., *Aureococcus* sp.
Summary: This study sought to determine if the brown tide absorption and chlorophyll fluorescence spectra differed from typical coastal phytoplankton. Comparisons were made between the diatom *Skeletonema* sp. and the brown tide organism, *Aureococcus* sp. The brown tide, unlike the diatom, indeed selectively absorbed

blue light in the same region as that for theoretically maximal photosynthesis in sea grasses (450 nm), greatly changing the subsurface light quality. Selective absorbance of blue light is a typical characteristic of oceanic phytoplankton. Using these results, the authors speculate that remote sensing could successfully indicate presence of brown tide-like organisms in coastal waters via fluorescence excitation spectra and/or colorimetry.

Methods: See "Methods."

QA/QC: None *per se*; see "Methods."

Contact: Charles S. Yentsch

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XVI. Acknowledgments

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