# TOXIC ALGAL BLOOMS AND RED TIDES: A GLOBAL PERSPECTIVE

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## ABSTRACT

The literature on toxic algal blooms and red tides documents a global increase in the frequency, magnitude, and geographic extent of these events over the last two decades. Some of this increase is undoubtedly a result of the increased awareness and analytical capabilities of the scientific community, but a strong correlation between the number of red tides and the degree of coastal pollution or utilization of coastal waters for aquaculture argue that there are other contributing factors. It also appears likely that toxic algal species have spread within regions over spatial scales of hundreds of kilometers, moving with major water currents and storms. Long distance transport of species across oceans may have occurred as well, but the evidence is not conclusive and the hypothesis controversial.

## BACKGROUND

Red tides, both toxic and non-toxic, have occurred throughout recorded history, but in recent years, there has been a global increase in the number of these events. This trend is most easily seen in the number of countries represented at international conferences on the subject. In 1974, the First International Conference on Toxic Dinoflagellate Blooms [1] had participants from 3 countries; the second conference in 1978 [2] represented 17 countries, and the third in the series in 1985 [3] had 22 participating countries. Now at this First International Symposium on Red Tides we have participants from 27 countries. At each meeting, outbreaks were reported for the first time at a variety of locations. In 1974, the major new concern was the massive 1972 New England red tide; in 1978, Paralytic Shellfish Poisoning (PSP) caused by Spanish mussels was recorded, as was a mysterious gastro-intestinal illness caused by Dutch mussels from clean, unpolluted waters; in 1985, toxic events were reported for the first time in the Faroe Islands, in Argentina, in Thailand and in Newfoundland Canada, and the gastro-intestinal illness first publicized in 1978 was shown to be of dinoflagellate origin and termed Diarrhetic Shellfish Poisoning (DSP). At the 1987 Symposium on Red Tides, more new outbreaks have been described, including brown tides in Rhode Island and New York that kill shellfish and submerged aquatic vegetation, or PSP in shellfish from Tasmania, Taiwan, Guatemala, Korea, Hong Kong, and Venezuela.

This sequence obviously neglects other events reported in the open literature (especially those concerning toxicity or mortalities associated with non-dinoflagellates) and is biased against contributions from Southeast Asia because of its geographic distance from the North American conferences, yet the overall impression is unmistakably one of a major expansion of the geographic extent, frequency, magnitude, and species complexity of red tides throughout the world. The obvious question is whether this expansion is truly occurring, or is instead a result of other factors such as the increased number of scientists working in the field or


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the increased sophistication and accuracy of analytical equipment. There is no easy answer to this question, but it is worthwhile to scrutinize the data more closely with these concerns in mind. Restricting our attention to toxic blooms because they are most reliably documented in the literature or in unrecorded folklore, the number of first occurrences or possible spreading events from the last two decades can be grouped into three categories. This compilation is by no means comprehensive, but does include examples of a variety of different phenomena.

## Dispersal Within a Region

Included in this category are those events where there is reason to believe that a toxic algal species was present within a region from which it then expanded its geographic range on spatial scales of hundreds of kilometers. The best example is the 1972 New England red tide [1], which caused PSP along the southern New England coastline where there had been no previous records of shellfish toxicity. Every year since that event, PSP has occurred in that region, often in historically-popular clamming areas. Based on health records and local folklore as well as more sophisticated scientific analysis using isozyme electrophoresis [4], this is one case where it can be said with surety that spreading did occur in 1972 from established populations that had long caused toxicity in northeastern Canada and Maine. Similarly, in late 1975, a bloom of *Pyrodinium bahamense* in Papua, New Guinea (where toxic red tides were common events) was followed in early 1976 by the first reported PSP episode in Sabah and Brunei [5]. It has been suggested that this transport was via the Southern Equatorial Current, but a scarcity of plankton records and the uncertainties of interviews with inhabitants make it difficult to prove that this was a true spreading event. Nevertheless, a PSP outbreak in the Philippines in 1983 may represent further dispersal of *P. bahamense* within the region.

## Introduction to a Region

This category includes events where the causative algal species may have been introduced to a region from far away - even across oceans. This is by far the most controversial category, since it is easier to argue that a species was present in a region at low concentrations and escaped detection than to prove that it was never there at all. One possible example of long-distance spreading involves *Gyrodinium aureolum*, a dinoflagellate which was not observed in an extensive series of plankton counts in the North Sea until 1966 [6]. Within two years, that species was blooming and causing fish kills that are a serious problem to the western European fish farming industry to this day. In northwest Spain, episodes of PSP began unexpectedly in 1976 in an area with an extensive mussel farming industry. The causative organism was *Gymnodinium catenatum*, which subsequently bloomed in 1985, 1986, and 1987. Phytoplankton counts dating back many years in that region and a long history of shellfish consumption and culture both suggest that *G. catenatum* is an introduced species. In 1985, this same species was linked to PSP in Tasmania, Australia for the first time, and as in Spain, there is speculation that the species was introduced. Plankton records suggest that *G. catenatum* was present in 1980, but apparently not before [7]. Originally described in 1942 in Mexico, this species has been reported in only four other widely-scattered locations - Argentina, Spain, Tasmania, and Japan.

Another new and disturbing event is the 1987 outbreak of PSP in Champerico, Guatemala that killed 26 people [8]. As usual, historical evidence for the complete absence of past toxicity in that region is not conclusive, but again there has been speculation that the problem is introduced. Here the important observation is that the causative organism is P. bahamense, a dinoflagellate reported in tropical waters of the western hemisphere but never directly associated with toxicity. Part of the uncertainty here is that there are two strains of P. bahamense, the toxic variety compressa and the non-toxic variety bahamense. Early reports of this species in Central and South America have typically specified variety bahamense or have not provided sufficient detail for a proper designation. In Champerico, P. bahamense var. compressa caused the PSP, so there is concern that the the toxic variety that has caused fatalities and economic hardship in Southeast Asia has now crossed the Pacific. Just as we saw an apparent dispersal of this organism between Papua, New Guinea and Sabah, Brunei, and the Philippines in the last ten years, will there now be a spreading of PSP in Central America and the Caribbean? It is a disturbing prospect.

## Unusual Conditions

In this category, a toxic species may have been present in an area for years, but a unique set of conditions favorable for growth or accumulation allowed that species to fluorish at one point in time. A clear example is the 1982 outbreak of PSP in Newfoundland, Canada. Since this island is near areas in northeastern Canada that have a long history of PSP, shellfish in Newfoundland have been tested since the 1950's. Results were always negative until 1982 when PSP reached dangerous levels immediately after two weeks of warm, sunny weather - a rare event in that region. A reasonable conclusion [9] is that the causative organism (Protogonyaulax tamarensis) had been in those waters for years, but conditions had never been right for the cells to bloom. In 1983, an outbreak of PSP occurred in the Gulf of Thailand, caused by a species of dinoflagellate new to the growing list of toxin producers - Protogonyaulax cohorticula. The episode was sudden and unexpected, and has not recurred.

Perhaps the most important new occurrence among the list of unusual events is the "brown tide" that first appeared in parts of the northeastern United States in 1985 [10]. The organism is a previoulsy undescribed chrysophyte named Aureococcus anorexefferens. Its blooms are so dense that shellfish either stop filtering or retain very little food and starve to death. The blooms also block the sunlight and thus destroy eelgrass beds, an important habitat for scallops and other marine organisms. Aureococcus anorexefferens is such a tiny (2 µm) featureless organism that it is difficult to say whether it was ever present prior to the 1985 blooms. It has since bloomed in 1986 and 1987 as well and has devastated the multi-million dollar scallop resource on Long Island. Although this organism might have spread from elsewhere, it seems more likely that it was a minor component of the local phytoplankton assemblage that fluorished under unusual conditions. The only record of a similar occurrence is an unpublished report from France where oysters died of starvation during a bloom of a tiny, unnamed picoplankter that turned the water brown for several months [11].

## Contributing Factors

There are a number of possible explanations for the increased number of reports of red tides or toxicity episodes throughout the world during the last 20 years. These can be summarized as follows:

1) The scientific community is better informed and more alert for the signs and symptoms of plankton blooms and toxicity episodes. Analytical capabilities have improved considerably as well, making it much easier to detect toxins. The 1985 PSP outbreak in Tasmania is an interesting issue in this context, since toxicity was detected shortly after a major marine

laboratory moved to the island from the mainland of Australia. Gymnodinium catenatum may still have been a recent introduction to the area during the years prior to that discovery, but there is no doubt that the prompt diagnosis of PSP and the isolation of the causative organism was in part due to the increased scientific scrutiny of local waters.

2) The use of coastal waters for shellfish and finfish farming can amplify an area's existing toxicity potential. Not only are the products of marine farms monitored and assayed very carefully, but the nutrient enrichment of local waters from the food and excretion of the cultured animals could stimulate red tide phytoplankton. The introduction of a shellfish or finfish resource could also make an existing toxic organism more noticeable. For example, over the years there had been sporadic reports of illnesses among humans eating Anadara and other shellfish from Balete Bay in the Philippines, but one year after the green mussel was first successfully cultured in the bay, PSP was detected [12]. Mussels are well-known for their ability to accumulate PSP toxins more rapidly than other filter feeders

3) Even though old plankton records do not document the existence of certain species, collection and preservation techniques were often inadequate and the resulting species identifications should be considered incomplete. The use of plankton nets with large mesh sizes or the preservation of samples with 10% formalin as was common in the past would have biased observations against smaller species or those that deform or are destroyed by strong fixatives (a particularly serious problem with naked or fragile flagellates such as G. aureolum or G. catenatum).

Dispersal Mechanisms

Although the above explanations can account for some new reports of toxicity, there is no doubt that certain spreading events are genuine. The dispersal of a species within a region by currents or other major water movements is not only possible but probable, the 1972 New England red tide being a noteworthy example. But how can we explain the introduction of a species to a region thousands of kilometers from its source? In this context, it must be stressed that many of our toxic red tide species form resting stages (e.g. Protogonyaulax species, G. catenatum, Chatonella antiqua, P. bahamense) and that these resistant cells can remain fully viable under harsh conditions. One possible transport mechanism is in the ballast water of ships. Cells taken into the ballast in one port could either survive as motile cells for short distances or as cysts for longer trips before being discharged into the water at the ship's destination. An excellent review of the importance of this mechanism in the biogeography of many marine animals is given by Carlton [13], and there is every reason to believe that toxic algal species have travelled in similar fashion. It is also important to note that since cysts are rapidly buried below the sediment surface where many do not germinate until they are resuspended, the introduction of a species to an area is often followed by years of recurrent outbreaks. It is easy for cyst-forming species to be introduced to a region, but their eventual disappearance is a long, gradual process.

The other side of the spreading or dispersal argument deserves discussion as well - namely that in an evolutionary sense, phytoplankton have had ample time to reach and inhabit suitable environmental niches throughout the world and thus that recent spreading is unlikely. Taylor [14] argues that similar environments in different oceans typically have the same general plankton assemblage. Whereas marine animals or other less primitive organisms may need man's inadvertant assistance to disperse to new regions, phytoplankton species may have already achieved a stable distribution.

Although these two points of view on spreading are difficult to reconcile in hindsight, there are ways to compare geographically-distant populations. For example, electrophoretic analysis of _P. tamarensis_ isolates from the east coast of the US and Canada revealed a genetically homogeneous population, consistent with the hypothesized recent dispersal from a common source during the 1972 New England red tide [4]. A similar analysis of isolates from the west coast showed far more diversity among strains [15], as would be expected given that region's long history of PSP. Although similar approaches would be highly informative when applied to isolates of _G. catenatum_ or _P. bahamense_ from distant locations to examine the spreading hypothesis, the truly definitive information requires molecular taxonomy using RNA sequencing or cloned DNA probes. Another method for studying species dispersal is based on the ability of both _P. bahamense_ and _G. catenatum_ to form resting cysts with resistant cell walls. This means that if one of these species was present in a region hundreds or thousands of years ago, the cyst walls would still be present in the sediment. A coring study that examined sediments below the well-mixed zone where bioturbation activity is high could thus determine whether a species was newly introduced to a region or not.

## Long-Term Trends

In addition to the spreading mechanisms and contributing factors discussed above, we cannot ignore the possibility that long-term trends in pollution or natural environmental parameters can be major factors in that increase. It is now firmly established that there is a direct correlation between the number of red tides and the extent of coastal pollution, measured either as the chemical oxygen demand of effluents as in Japan [16] or the population density in a watershed as in Hong Kong [17]. The reason that some noxious or toxic phytoplankton dominate other species in polluted waters remains a mystery, and it is not clear whether this correlation holds for PSP-producing species such as _P. tamarensis_ or _P. bahamense_, but the fact remains that man's activities in the coastal zone can directly affect the incidence of red tides. There may, however, also be natural environmental trends that affect the growth and dominance of certain phytoplankton. For example, a long-term dataset from the central north Pacific Ocean documents a statistically-significant doubling in the chlorophyll content of the mixed layer over the last 20 years [18], presumably due to a decrease in sea surface temperature. In coastal waters, data from Narragansett Bay, Rhode Island since 1959 [19] document: 1) an increase in the annual average water temperature by almost one degree Celsius; 2) a 10% decrease in the annual average wind speed; 3) a corresponding decrease in the depth of light penetration in the water column; and 4) an increase in the abundance of non-diatom phytoplankton, especially since the late 1970's. These data suggest that global environmental trends may be superimposed on effects due to pollution, spreading, or other factors. To detect such trends, we need long-term datasets similar to those described above. One useful parameter in such monitoring efforts would be shellfish toxicity since regular assays at the same stations can reveal important trends (such as the surprising increases in PSP toxicity in eastern Canadian shellfish over the last several decades [20]). Toxin monitoring efforts could be included in a global "Mussel Watch" program similar to that established in the US to detect trends in trace metal and organic pollutants.

At a practical level, there is little we can do to prevent the spreading of species by currents and major water movements, nor can we expect to regulate ship ballast or other accidental dispersal mechanisms. However, it is possible to control pollutants, especially when the increasing political power of aquaculture interests are brought to bear on the problem, but here again, the economic pressures on under-developed countries may preclude expensive pollution control strategies. What is needed is a way to help countries anticipate and manage problems from algal blooms when they arise. Existing techniques make it relatively easy to conduct surveys on a regional level to find the cysts or motile stages of dangerous organisms, a precaution that would be most useful in areas where fisheries developments are being planned or where there is an existing industry worth protecting. The technology and expertise for such studies exists, but is often not found in the countries most needful of the information. We clearly need a degree of formal international cooperation and training that does not exist at present. Several international working groups on red tides have been established in recent years, and attempts are underway at the Intergovernmental Oceanographic Commission to coordinate red tide training and information exchange even further. These are worthwhile efforts, but we must do more. The red tide problem is a global issue and should be formally recognized as such. If we continue to conduct our research in relative isolation, communicating mainly through the literature or at conferences, we may miss the opportunity to document and respond to immensely important trends or spreading events.

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