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Some observations on harmful algal bloom (HAB) events along the coast of Guangdong, southern China in 1998

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Abstract

The year 1998 was an unusual year for Guangdong Province and Hong Kong, both in southern China, as the frequency and intensity of harmful algal blooms (HAB) were much higher than usual. This paper describes the causative organisms found associated with these blooms and speculates on the possible causes of these blooms, including the effects of increased temperature, reduced salinity, eutrophication and meteorological and oceanographic events on the initiation and spread of these blooms.

Introduction

The occurrence of red tides in the South China Sea (SCS) has been monitored over the last decade (Qi et al., 1992, 1993; Hodgkiss & Yim, 1995; Liang, 1996; Hodgkiss & Ho, 1997; Hodgkiss & Lu, 2004). In about 50% of these cases, these red tide events were due to the dinoflagellate *Noctiluca scintillans*. However, other causative organisms like *Skeletonema costatum* (Grev.) Cleve, *Pseudo-nitzschia pungens* (Grunow *ex* Cleve) Hasle, *Chaetoceros* spp. and *Rhizosolenia longisima* were also often found to occur in the bloom. In 1998, massive harmful algal blooms (HAB) occurred along the coast of Guangdong Province and Hong Kong in southern China. These HABs differed from those occurred in the previous years in that the causative species were diverse (Table 1). They were toxic or potentially toxic (Lu & Hodgkiss, 1999, 2004; Yang et al., 2000a,b) and inflicted significant negative impacts on the society. They devastated aquaculture and destroyed natural marine ecosystems, with a tremendous economic loss estimated at over 0.3 billion Chinese yuan (about 35 million US$).

This paper gives an overview of HABs in the coastal waters of Guangdong and Hong Kong in 1998, and explores the possible initiating factors to explain why so many HAB events occurred in this area at this time.

Materials and methods

Water sampling

The sea areas covered in this investigation included mainly the coastal waters of Guangdong and Hong Kong (Fig. 1). For every area that experienced algal bloom, samples were taken at every 3- or 6-day interval using a 20-μm phytoplankton net and a 5-l water sampler. Phytoplankton were enumerated in the laboratory using a Sedgwick–Rafter counting cell.

Water quality analysis

Water quality analyses, including chlorophyll *a*, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and dissolved oxygen (DO) concentrations and water temperature (*T*) were conducted

Table 1. HABs on the coasts of Guangdong and Hong Kong in 1998

Date	Causative species	Area	Effect
February	*Phaeocystis globosa* Scherffel	Raoping, Guangdong	Fish kill
March 19	*Gyrodinium* and *Gymnodinium* spp.	Hong Kong	Fish kill
March 24	*Gymnodinium mikimotoi* Miyake et Kominami ex Oda	Dapeng Bay, Guangdong	Fish kill
April	*Gymnodinium mikimotoi*	Huidong, Guangdong	Fish kill
April	*Gymnodinium* sp.	Yangjiang, Guangdong	Fish kill
April 9–17	*Gymnodinium mikimotoi*	Zhuhai, Guangdong	Fish kill
April 22–May 2	*Gyrodinium instriatum* Freudenthal et Lee	Shenzhen Bay, Guangdong	None
April 23	*Gyrodinium aureolum* Hurlbert	Shenzhen Bay, Guangdong	Fish kill
May 2–5	*Gymnodinium mikimotoi*	Daya Bay, Guangdong	Fish kill
Sept. 5–9	*Scrippsiella trochoidea* (Stein) Loeblich III	Daya Bay, Guangdong	None
Sept. 29–Oct. 3	*Ceratium furca* Ehrenberg (Claparède et Lachmann)	Dapeng Bay, Guangdong	Beach closed
Nov. 7	*Noctiluca scintillans* (Macartney) Ehrenberg	Shanwei, Guangdong	None
Nov. 8–15	*Mesodinium rubrum* Leegaard	Daya Bay	None

following the standard protocol prescribed in 'Regulation of Ocean Investigation' by Chinese State Oceanic Administration (SOA), 1989.

Morphological observation of causative organisms

Morphological observation of the causative organisms of HAB was carried out using an Olympus BH-2 light microscope. For more detailed observation, scanning electron microscopic studies were conducted. DNA sequences of doubtful species were made to help in the species identification.

Results and discussion

Major causative species of HABs in 1998

Red tide causative species in 1998 were very different from those in the previous outbreaks. Some were new records, some were rare, some were probably new species (Yang et al., 2000a,b), but most were dinoflagellates.

Phaeocystis globosa *Scherffel (Fig. 2)*
In September 1997, a Haptophycean species, *Phaeocystis globosa*, bloomed in Quanzhou Bay, Fujian province (part of East China) and then spread down south to the Guangdong coast. The bloom covered an area over 3000 km^2 in size and lasted for about 6 months. It resulted in massive fish mortality and devastated the caged-fish aquaculture industry. The main species of fish killed were: *Scombermorus guttatus* (Bloch et Schneider), *Pampus chinensis* (Euphrasen), *Lutjianus chrysotaenia* (Bleeker) and *Pagrosomus major* (Temminck et Schlegel) [*Pagrus major*]. The estimated economic loss was more than 60 million Chinese yuan (about 7.5 million US$).

Phaeocystis colonies have long been noticed by local fishermen and the term 'red bubble' was used to describe these colonies. In Raoping county water area, the colonies began to appear in mid-October and the colony numbers reached a maximum on 20 November 1998. The average level of chlorophyll *a* near cage-fishing area was 10.2 $\mu g\ l^{-1}$. A large amount of foam accumulated on beaches, causing a great nuisance smell. Brownish colonies in the sea were big enough to be seen easily (the biggest one was over 30 mm in diameter). Both morphological forms – free-living motile cell and colony – have been identified in the natural samples. The motile cells possess two flagella and a haptonema, which is difficult to be observed under the light-microscope. Their sizes are about 3–5 μm

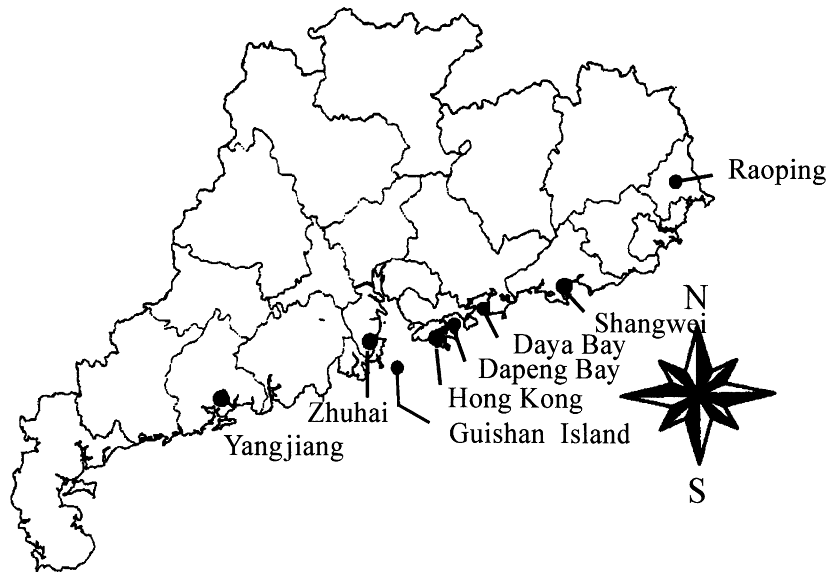

Figure 1. Map of Guangdong Province, China showing sites where HABs occurred in 1998.

(Fig. 2). Each cell contains about two to three parietal yellow-green chloroplasts. Colonies are shown to vary widely in size ranging from 20 μm to over 30 mm. These are composed of thousands of cells embedded in a mucilaginous matrix. Individual cells are distributed within the gel matrix of the homogeneous spheres.

Identification of this causative species was difficult. It closely resembled *Phaeocystis pouchetii* Lagerhein in colonial form, but was not lobed when it became ripe. The size was also bigger than that originally diagnosed for *P. pouchetii* (2 mm in diameter) (Sournia, 1988). DNA sequences confirmed that this species was *P. globosa*. The DNA sequencing analysis gave an interesting result and revealed that the species in China is somewhat different from the European and American strains (Medlin & Lange, 1994), showing that this strain is endemic.

Gymnodinium mikimotoi *Miyake et Kominami ex Oda (Fig. 2)*

The blooms caused by *Gymnodinium mikimotoi* in March to April stretched over almost all coastal areas across the Pearl River estuary from Huidong, east of Guangdong, to Yangjiang, west of Guangdong (Fig. 1). The highest density of *G. mikimotoi* was up to 2.08×10^6 cells l^{-1} in Guishan, Zhuhai. The bloom inflicted a loss of over 0.1 billion Chinese Yuan in aquaculture. A large number of fish, such as: *Seriola* sp., *Pagrosomus major*, *Epinephelus epistictus* (Temminck et Schlegel) were killed.

The causative organism of the red tide which occurred at the same time in Hong Kong was identified to be *Gyrodinium aureolum* (Yang & Hodgkiss, 1999). It is believed by some workers (e.g., Hallegraeff et al., 1995) that *Gymnodinium mikimotoi* and *Gyrodinium aureolum* are the same species. Whether or not these two organisms are the same remains to be verified in more details. Furthermore, Yang & Hodgkiss (1999) reported that another species occurred in Hong Kong in March and April is a new species of *Karenia*. They later named it *Karenia digitata* (Yang et al., 2000b). Also, the *K. digitata* bloom devastated caged fish aquaculture, resulted in over HK$ 0.3 billion (about 38 million US$) economic loses. These authors also found another new species, *Karenia longicanalis*, in mid-May, 1998 in Victoria Harbor, Hong Kong (Yang et al., 2000a). Further studies are needed to verify the identification of species from Hong Kong and the whole of Guangdong coast.

Gyrodinium instriatum *Freudenthal et Lee (Fig. 2)*

This species was not recorded previously in China, but has been noted as a red tide species in Japan (Fukuyo et al., 1990). A bloom caused by this species occurred in Shenzhen Bay from 23 April to 3 May 1998, covering an area of 200 km^2. High cell concentrations between 10^5–10^6 cells l^{-1} were observed at the caged fish area and the outer estuary (Fig. 3). The highest cell density was 3.8×10^6 cells l^{-1}. Although the nutrient contents were relatively high in the inner estuary of the Gulf of Shenzhen River, phytoplankton biomass was

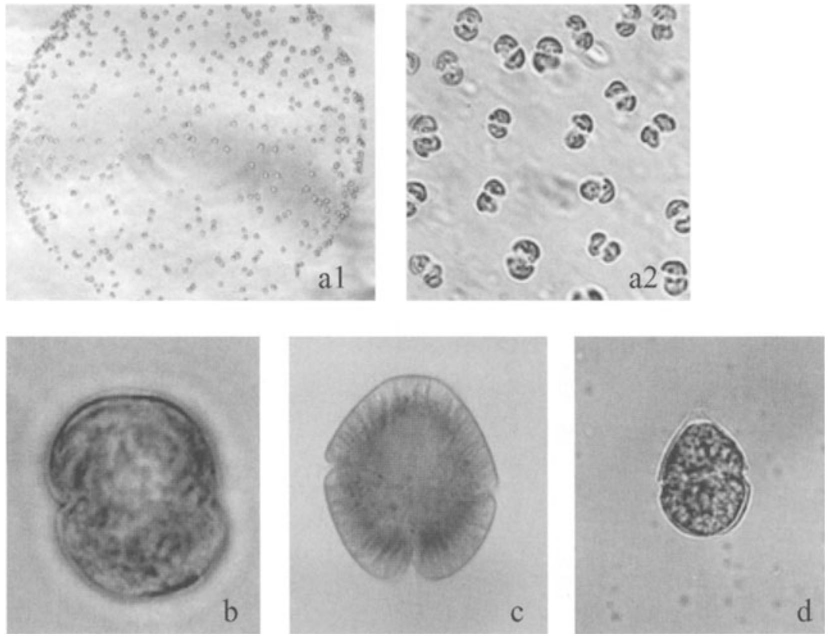

Figure 2. Representative causative bloom organisms. (a) *Phaeocystis globosa*; (a1) colony; (a2) pair cells in a colony; (b) *Gymnodinium mikimotoi*; (c) *Gyrodinium instriatum*; (d) *Scrippsiella trochoidea*.

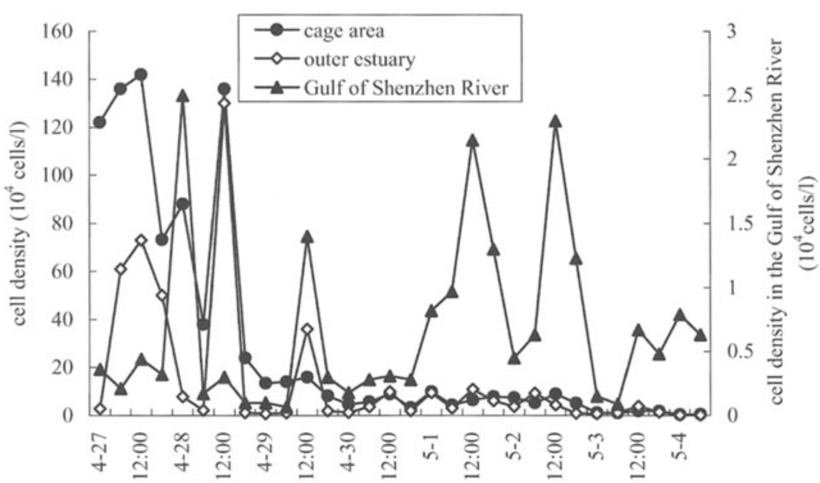

Figure 3. The quantitative variation of cell densities of *Gyrodinium instriatum* in Shenzhen Bay from 27 April to 4 May 1998 during the red tide bloom.

normally low due to heavy suspension of sediments. So far, there is no report showing this to be a toxic species and it did not cause any fish mortality this time.

Scrippsiella trochoidea *(Stein) Loeblich III (Fig. 2)*

This is a very common non-toxic species which often forms blooms in the coast of Guangdong. From 5 to 8 September 1998, a bloom of this species occurred in Daya Bay. The cell density was up to 6.3×10^5 cells l^{-1} (Wang et al., 1998).

Figure 4. Daily changes of air temperature in Shenzhen City from March to May, 1998.

Suspected causes initiating algal blooms in 1998

Many factors have been speculated to be responsible for initiating algal blooms. Among these are: (1) climate change and temperature, (2) meteorological and oceanographic features and (3) anthropogenic influences in the form of excess nutrient loading.

Climate change and temperature

The year 1998 was an El Niño year, and an unusual climate pattern was observed. For example, there was a high of up to 32 °C air temperature in Guangdong in March, but a low of 18 °C in May. Temperature is thought to be one of the most important factors initiating blooms (Liang & Qian, 1991; Qian et al., 1991). Algal bloom that occurred in March and April 1998 apparently coincided with a rise in temperature (Fig. 4). When the temperature increased from 21 to 25 °C, a *G. aureolum* bloom was initiated in Hong Kong waters on 9 March and then on 21 March. Another temperature variation apparently induced a *G. mikimotoi* bloom in Nan-au, Dapeng Bay, east of Hong Kong. Interestingly, on 24 April, when the temperature rose from 22 to 28 °C, a *Gyr. instriatum* bloom was observed in Shenzhen Bay. The northeast monsoon changes to southwest monsoon from March to May. During this period, the weather gradually becomes warmer. This period is also the beginning of the rainy season, with the wind velocity generally becoming weakened and the air pressure becoming lower. It is during this period that algal bloom could easily occur (Liang & Qian, 1991).

Precipitation also played an important role in the algal bloom in 1998. There were few rainfalls from March to early April in Guangdong in 1998. Rains became heavier and more frequent after mid-April. Heavy rain reduced the salinity of seawater. There was a heavy rainfall (28.3 mm) on 12 April, 1998 in Guishan Island area before the *G. mikimotoi* bloom. Marked decrease in the salinity of the surface layer by heavy rain was reported to be the important factor causing huge bloom of *G. nagasakiense*, a relative species of *G. mikimotoi*, in Japan (Yamaguchi, 1994). Similarly, *G. mikimotoi* bloom often occurred after heavy rain in Korea (Cho, 1981). In Shenzhen Bay, a heavy downpour from 26 to 27 April, 1998 recorded 126 mm of precipitation. This rain greatly reduced the salinity of the water around Shenzhen Bay to brackish level, and together with high nutrient levels and high temperature, induced the outbreak of *Gyr. instriatum* bloom.

Meteorological and oceanographic features

Effects of meteorological and oceanographic features on the occurrence of HABs are relatively poorly studied in China. This could be another key factor inducing HAB events.

Bloom distribution often depends on wind direction or flow of ocean currents. There are arguments as to where the HABs in 1998 originated, either in mainland or in Hong Kong waters. However, it is agreed that bloom movement should have been influenced by wind direction and current movement in either case, and that monsoon wind is an important element in determining the bloom direction in coastal waters of Guangdong in the spring. The spring monsoon blows in a southeast direction and this direction changes to northwest in winter. So, the HABs that occurred in the spring of 1998 probably started in Hong Kong waters, then moved to Dapeng Bay of mainland waters. Algal bloom expansion also followed the same phenomenon in Guishan, Zhuhai. *G. mikimotoi* first appeared on 8 April around Hong Kong waters and then spread to Guishan Island on 10 April. It was carried by current movement, generated from the southeast wind.

Anthropogenic impacts and excessive nutrient loading

Many studies have shown that water pollution is a key factor inducing HABs (Lancelot et al., 1987; Anderson, 1997). Wastes and raw sewage discharging into the sea without treatment often cause nutrient overloading which then easily induces bloom outbreaks. For instance, there were 2.8 billion t of sewage discharged into the estuary of the Pearl River in 1997, among which just 10% were given primary treatment. This causes excess input of nitrate and/or phosphate (eutrophication) and often results in HABs.

Another source of excessive nutrients is mariculture. Mariculture has increased dramatically along the coasts of China. There are now over 110 000 fish-cages in Guangdong province alone. Intensive aquaculture causes self-pollution as a result of excess feeding, fish feces and aging-water. A good example to elucidate the nutrient situation in caged fish areas is Ya-qian Bay, a small bay in Daya Bay (Fig. 1). The size of the bay is 23 500 m^2. Fish production was 132 t in 1997 and the total feed used amounted to 1056 t. There was a discharge of 48.9–131.8 kg of nitrogen into the sea for every ton of fish cultured. Within a year, 6.5–17.4 t of nitrogen in total would have been discharged into the sea. This figure does not include nitrogen from fish feces. This example clearly indicates that intensive aquaculture causes self-pollution. Long term aquaculture in the same area, over-crowded cage arrangement and intensive fish culture result in eutrophication of the marine aquaculture area, and thus offers a suitable environment for algae to grow and form blooms.

When a *G. mikimotoi* bloom occurred in April in Guishan, Zhuhai water (at the mouth of the Pearl River), the total inorganic nitrogen in the water was 211 $\mu g\ l^{-1}$, but the total inorganic phosphorus level was 7 $\mu g\ l^{-1}$. Meanwhile, when a *Gyr. instriatum* bloom happened in Shenzhen Bay at the end of April, the nitrogen level was up to 977 $\mu g\ l^{-1}$. Moreover, at the mouth of the Shenzhen River, the ammonia nitrogen level was 4500 $\mu g\ l^{-1}$. There are many examples indicating that nutrients are a key factor in initiating algal blooms (Liang, 1996).

HAB formation is a complicated phenomenon. We need to put more effort into exploring its mechanisms. There is a need to synthesize approaches from biology, ecology, oceanography and meteorology.

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