The **red tide**

Photo courtesy of Suisan Aviation, Japan

Noctiluca scintillans is the culprit which caused this spectacular, if harmless, 'red tide' in the Seto Inland Sea in 1976. Red tides are a frequent occurrence along the coast of Japan

Of the 5000 species of marine phytoplankton, 300 can proliferate to such an extent that they discolour the surface of the sea, producing an impressive 'red tide' made up of millions of cells per litre of water. The microscopic algae which make up these blooms are a delicacy appreciated by oysters, mussels, scallops and clams. Moreover, as both shellfish and the larvae of crustaceans and finfish find microalgae a tasty morsel, red tides can be a veritable boon for aquaculture and wild fisheries.

In some situations, however, these spectacular algal blooms can turn into a nightmare, causing severe economic losses to aquaculture, fisheries and tourism, major environmental problems and health 'epidemics'. Only 80 or so microalgal species may be able to produce toxins potent enough to find their way through fish and shellfish into humans but, for the victim of food poisoning, the consequences can be tragic.

Harmful blooms are becoming more frequent, more intense and more widespread. Researchers, industrialists, governments and local users will be meeting in Copenhagen (Denmark) from 4 to 8 September to exchange research findings and ideas on how to cope with this escalating problem, at a conference co-sponsored by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Worldwide, close to 2000 cases of food poisoning from consumption of contaminated fish or shellfish are reported each year. Some 15% of these cases will prove fatal. If not controlled, the economic damage through the slump in local consumption and exports of seafood products can be considerable.

Whales and porpoises can also become victims when they receive toxins through the food chain via contaminated zooplankton or fish. In the USA, poisoning of manatees in Florida via seagrasses and, in California, of pelicans and sealions via anchovies, has been reported.

A nuisance even in biblical times

One of the first recorded fatal cases of food poisoning after eating contaminated shellfish happened in 1793, when English surveyor Captain George Vancouver and his crew landed in British Columbia (Canada) in an area now known as Poison Cove. He noted that, for local Indian tribes, it was taboo to eat shellfish when the seawater became bioluminescent due to algal blooms. The toxins involved, paralytic shellfish poisons (PSP), are so potent that a quantity the size of a pinhead (about 500 micrograms), which can easily accumulate in just a 100-gram serving of shellfish, can be fatal to humans.

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Aerial and ground views of a megascale shrimp farm in Indonesia made up of 18 000 ponds

It is believed that the first written reference (1 000 years B.C.) to a harmful algal bloom appears in the Bible: 'All the waters that were in the river were turned to blood. And the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river' (Exodus 7: 20–21). In this case, a non-toxic alga became so densely concentrated that it depleted the oxygen in the water, thereby suffocating both fish and invertebrates. Non-toxic algal blooms can thus be devastating for local ecosystems, not to mention scaring away tourists confronted with unsightly dead floating fish, slime and foam.

Harmful algal events on the rise

Harmful algal blooms are completely natural phenomena which have occurred throughout recorded history but, in the past two decades, they seem to have become more frequent, more intense and more widespread. PSP, for example, was only known in temperate waters of Europe, North America and Japan until 1970. Twenty years later, PSP was well-documented throughout the Southern Hemisphere, in South Africa, Australia, New Zealand, India, Thailand, Brunei, Sabah, the Philippines and Papua New Guinea. It is unfortunate that so few long-term records of algal blooms at any single locality exist.

Four explanations for this apparent increase in algal blooms have been proposed: a greater scientific awareness of toxic species; the growing utilization of coastal waters for aquaculture; the stimulation of plankton blooms by domestic, industrial and agricultural wastes and/or unusual weather conditions; and the transportation of algal cysts either in ships' ballast water or associated with moving shellfish stocks from one area to another.

Know thine enemy

Reports of harmful algal blooms, associated human illnesses or damage to aquaculture operations, are receiving growing attention in newspapers, the electronic media and scientific literature. As a result, more and more researchers are now surveying their local waters for the algal culprits.

Since diarrhetic shellfish poisoning (DSP) was first documented in 1976 from Japan, where it caused major problems for the scallop fishery and provoked 1 300 cases of food poisoning in six years, other outbreaks have been reported: more than 5 000 cases in Spain in 1981 and a further 3 300 cases in France in 1983. In 1984, DSP caused a shutdown of Sweden's mussel industry for almost a year. As the clinical symptoms of DSP may often have been mistaken in the past for those of bacterial gastric infections, the problem may be much more widespread and serious than previously thought.

Amnesic shellfish poisoning (ASP) was first identified in 1987 on Prince Edward Island, Canada, where it caused three deaths and 105 cases of acute food poisoning following the consumption of blue mussels.

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A seafood lunch in a Bangkok restaurant in Thailand. Until 1970, cases of paralytic shellfish poisoning (PSP) had only been reported in the Northern Hemisphere but, by 1990, PSP had spread to South Africa, Australia, New Zealand, India, Thailand, Brunei, Sabah, the Philippines and Papua New Guinea

Pollution alert

Red alert… commercial fisherman Ted Allan is photographed by Julian Andrews holding a sample of red algae at Little Manly on Australia's west coast on 18 February 1997. The Manly Daily *reported that 'swimmers were warned to stay out of the water yesterday as a tide of red algae washed into Manly Cove and stormwater fouled Queenscliff beach'. The photo on the right showing the red tide caused by* Noctilluca scintillans *was taken by R. Chan and S. Murray of the University of New South Wales in Australia*

Algae like aquaculture

To combat overfishing in coastal waters, more and more countries are turning to aquaculture as an alternative. Fisheries scientists predict that, within the next 10–20 years, the increasing value of world aquaculture production may well approach the decreasing value of the total catch of wild fish and shellfish. The increase in shellfish farming worldwide is leading to more reports of paralytic, diarrhetic, neurotoxic or amnesic shellfish poisoning. It is also drawing attention to algal species which can cause damage to the fishes' delicate gill tissues or even kill the fish altogether. Whereas wild fish stocks are free to swim away from problem areas, caged fish are trapped. In 1972, in Japan, one algal bloom killed US$500 million worth of caged yellowtail fish in the Seto Island Sea.

Norway has found a solution. On the coast, it has installed sophisticated monitoring systems using buoys with fibre optical sensors and data transfer by satellite; this allows cages to be towed away from bloom-affected areas. During the 1988 bloom, more than 26 000 tons of fish in 1 800 cages were thus moved from their permanent site to inland fjords.

Another way of limiting caged fish losses is to stop feeding the fish, since feeding attracts the fish to the surface and increases oxygen demand. Or you can pump water into the cages to dilute the algal concentration and harvest the marketable fish before the algal bloom can get to them.

When poisonous blooms infest freshwater

One concern is that domestic, industrial and agricultural waste is stimulating bacterial blooms (cyanobacteria or blue-green algae). Cyanobacteria are one of the largest groups of bacteria on Earth – and one of the oldest: fossils have been found dating back more than 3.5 billion years!

Global distribution of paralytic shellfish poisoning in 1970 and 2000. A mild dose of poisoning causes numbness, headache, dizziness, vomiting and diarrhoea. The patient's stomach is pumped and there are no lasting effects. In extreme cases, it can cause death through respiratory failure 2–24 hours after consumption of the contaminated shellfish

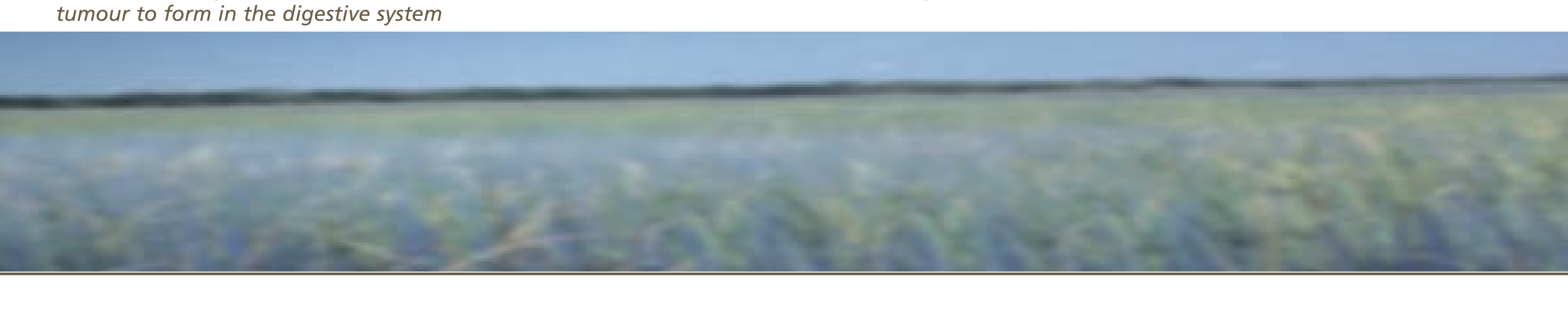
There are both freshwater and marine cyanobacteria and not all species are toxic. The freshwater cyanobacterium *Spirulina*, for example, is a valuable source of protein harvested traditionally by the Aztecs of ancient Mexico and by Africans living around Lake Chad. It is consumed widely around the world today, including as a health food. Many other species of cyanobacteria, however, are toxic to humans and animals.

Deforestation, farming and other changes in land-use may be contributing to the current proliferation of harmful freshwater cyanobacteria. The agricultural run-off of phosphorus can stimulate blooms which form a blue-green scum on the surface of ponds, lakes and reservoirs. These blooms are capable of killing domestic and wild animals – and even people. There have been reports of human intoxication in Australia, Bangladesh, China, 12 European countries, India, Israel, Japan, Latin America, North America, South Africa, Thailand and the former Soviet Union.

Unlike with marine algal blooms, the most common public health risk in freshwater does not arise from the accumulation of algal toxins in the digestive system of shellfish but rather from drinking water directly contaminated with teratogens (which cause malformations in embryos) and cyanobacteria toxins which, over time, may favour the development of tumours.

Several North European countries, as well as Hong Kong and Japan, have now agreed to reduce phosphate and nitrate discharges by 50% over the next few years. This is a move in the right direction but their efforts will almost certainly be in vain if their neighbours keep polluting.

Global distribution of diarrhetic shellfish poisoning in 1990 and 2000. After eating contaminated shellfish, a person will experience diarrhoea, nausea, vomiting and abdominal pain within a few hours which will last about three days, irrespective of treatment. Chronic exposure can cause a tumour to form in the digestive system



Global distribution of amnesic shellfish poisoning (ASP) in 1990 and 2000. The symptoms are the same as for DSP in mild cases. As its name suggests, ASP can cause short-term memory loss in extreme cases, as well as hallucinations and seizures

Whether the weather is to blame

There is a harmful alga by the name of *Pyrodinium bahamense* which is presently confined to tropical, mangrove-fringed coastal waters of the Atlantic and Indo-West Pacific. A survey of fossils going back to the warmer Eocene 50 million years ago indicates a much wider range of distribution in the past. For example, in the Australasian region at present, the alga is not found farther south than Papua New Guinea but, some 100 000 years ago, the alga ranged as far south as Sydney Harbour. There is genuine concern that, with an increased greenhouse effect and warming of the oceans, this species may return to Australian waters.

In the tropical Atlantic, in areas such as Bahia Fosforescente in Puerto Rico and Oyster Bay in Jamaica, the glowing red-brown blooms of *Pyrodinium* are a major tourist attraction. At first considered harmless, *Pyrodinium* blooms gained a more sinister reputation in 1972 in Papua New Guinea after red-brown water discolorations coincided with the fatal food poisoning of three children in a seaside village, diagnosed as PSP. Since then, these toxic blooms have apparently spread to Brunei and Sabah (1976), the central (1983) and northern Philippines (1987) and Indonesia (North Mollucas). There is strong circumstantial evidence of a coincidence between *Pyrodinium* blooms and inhabitual weather linked to the El Niño-Southern Oscillation[1] in 1991–1994.

Pyrodinium is thus a serious public health and economic problem for these tropical countries, all of which depend heavily on seafood for protein. In the Philippines alone, *Pyrodinium* has now been responsible for more than 2000 human illnesses and 100 deaths resulting from the consumption of contaminated shellfish as well as sardines, anchovies and the like. Most unexpectedly, during a *Pyrodinium* bloom in 1987 on the Pacific coast of Guatemala, 187 people had to be hospitalized and 26 of them died. In 1989, another bloom swept northward along the Pacific coast of Central America, again causing illness and death.

Global distribution of ciguatera fish poisoning. The mild symptoms are the same as for DSP and ASP but take up to 24 hours to develop. In extreme cases, balance, blood pressure and heart rate can be adversely affected. Respiratory failure can even cause death. There is no treatment available and neurological symptoms can last for months or even years

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Men fishing on a freshwater lake in South Africa, one of dozens of countries where toxic microalgae have been known to kill unsuspecting cattle drinking from ponds, lakes or reservoirs and to intoxicate people

Until recently, neurotoxic shellfish poisoning (NSP) was considered to be endemic to the Gulf of Mexico and the east coast of Florida, where red tides had been reported as early as 1844. An unusual feature of NSP is the formation by wave action of toxic aerosols which can lead to respiratory asthma-like symptoms in humans. In 1987, a major Florida bloom was dispersed by the Gulf Stream northward into North Carolina waters, where it has since persisted. Unexpectedly, in early 1993, more than 180 human shellfish poisonings were reported from New Zealand. Most likely, this bloom was triggered by the unusual weather conditions at the time, including higher than usual rainfall and lower than usual temperature, which coincided with El Niño.

Green mussel farm in the Philippines

Obtain an IOC certificate in identification of harmful algae

Since 1993, the UNESCO-IOC has run training courses in the identification of harmful microalgae via its Science and Communication Centre on Harmful Algae at the University of Copenhagen and in cooperation with the University of Tokyo.

As of this year, the IOC is awarding certificates of proficiency in identification and enumeration of harmful marine micro-algae to scientists and technicians from IOC Member States. The IOC has been inspired to redesign its courses by the example of the Natural History Museum in London, which has been offering this type of course for other species groups since 1993.

'We know from experience that many of the more than 500 trainees we have had over the years have wished the courses to give accreditation', observes Henrik Enevoldsen from the IOC's centre in Denmark. 'In New Zealand and elsewhere, the IOC courses have even become a reference for laboratories seeking approval to carry out regulatory monitoring of harmful microalgae'.

The new training framework offers accreditation by examination either via a training course or solely by examination for those with existing skills. In both cases, the certificate is awarded by the competent IOC partner institution which organizes the examination.

The training courses consist of an Internet (e-learning) teaching programme followed by a practical workshop. The first course got under way in May with an e-learning part equivalent to approximately one working day per week for six weeks. The practical part of this course is to take place at the University of Copenhagen from 10 to 18 September.

Two more courses will be run back to back in the first quarter of 2007, the first on identification and the second on enumeration of harmful marine microalgae. Applications will be open between 1 October and 1 January.

For details: http://ioc.unesco.org/hab/courses.htm

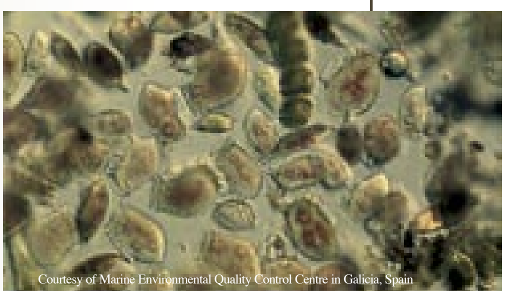
Ciguatera is a tropical fishfood poisoning syndrome well-known in coral reef areas in the Caribbean, Australia, and especially French Polynesia. Whereas, in a strict sense, this is a completely natural phenomenon (the English explorer Captain James Cook suffered from this illness when visiting New Caledonia in 1774), from being a rare disease two centuries ago, ciguatera has now reached epidemic proportions in French Polynesia. From 1960 to 1984, more than 24 000 patients were reported from this area, which is more than six times the average for the Pacific as a whole. Evidence is accumulating that reef disturbance by hurricanes, military and tourist developments, as well as coral bleaching (linked to global warming) are increasing the risk of ciguatera.

Algal stowaways

Ballast water is seawater which has been pumped into a ship's hold to steady it by making it heavier and thus less likely to roll; the water is released when a ship enters port. Ballast water on cargo vessels was first suggested as a means of dispersing marine plankton some 90 years ago. However, it was only in the 1980s that the problem sparked considerable interest, after evidence was brought forward that non-indigenous toxic species had been introduced in Australian waters into sensitive aquaculture areas, with disastrous consequences for commercial shellfish farms.

There is now considerable evidence that ballast water does transport marine organisms other than microscopic algae, including species of seaweed, fish, crustaceans, starfish and molluscs.

On February 2004, the International Maritime Organisation ratified the introduction of guidelines for ballast water handling procedures by bulk cargo vessels. These measures aim to reduce the risk of harmful introductions by encouraging a range of



A close-up look at Gymnodinium*, a microalga capable of causing paralytic shellfish poisoning, and of* Dinophysis *which causes diarrhetic shellfish poisoning*

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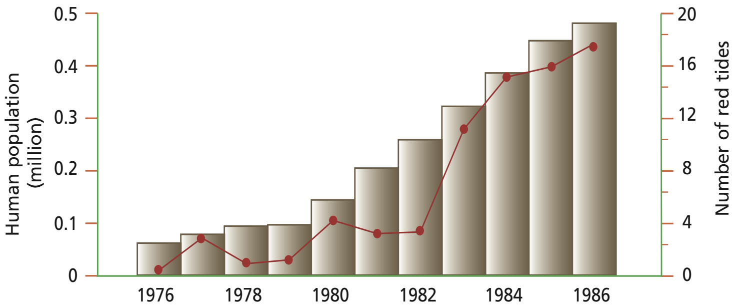
*Mass killing. Japanese fishermen set about the grim task of reaping a dead harvest of caged yellowtail fish (*Seriola quinqueradiata*) after the toxic algae* Chattonella Antigua *decimated the 'crop' in the Seto Inland Sea in August 1977*



There is a clear correlation between the number of red-tide outbreaks per year in Tolo Harbour (continuous line) between 1976 and 1986 and population growth in Hong Kong (bar diagram) over the same period[2].

practices such as reballasting at sea (only feasible for vessels up to 40 000 dead weight tonnage), ballasting in deep water, and disposal of ballast tank sediments away from sensitive aquaculture or marine park areas. The most effective measure to prevent the spreading of microplanktonic cysts via ships' ballast water would be to avoid ballasting during toxic blooms in ports. Other options using heat, electrical shock or chemical treatment of ballast water, either in the hold or in onshore facilities, have also been explored.

A growing menace: reality or myth?

Whether the apparent global increase in harmful algal blooms represents a real increase or not is a question that we will probably not be able to answer conclusively for some time to come. There is no doubt that our growing interest in using coastal waters for aquaculture is leading to a greater awareness of toxic algal species. What researchers are faced with today are signs of a truly global epidemic in terms of the effect on public health and the economic impact of harmful algal blooms. It is time to react. In countries which pride themselves on having disease- and pollution-free aquaculture, every effort should be made to quarantine sensitive aquaculture areas against the unintentional introduction of non-indigenous harmful algal species. Nor can any aquaculture industry afford not to monitor for an increasing number of harmful algal species in water and for an increasing number of algal toxins in seafood products.

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Mass mortality of flat-fish at a culture farm in the Republic of Korea. The culprit here is Cochlodinium polykrikoides

Most importantly, people responsible for deciding quotas for pollutant loadings of coastal waters, or for managing agriculture and deforestation, should be made aware that one probable outcome of allowing polluting chemicals to seep into the environment will be an increase in harmful algal blooms.

Last but not least, studies looking into El Niño, greenhouse effects and ozone depletion etc. need to consider the possible impact of global climate change on algal bloom events. A number of new international programmes have been launched to study and manage harmful algal blooms and their linkages to environmental changes in a manner consistent with the global nature of the phenomena involved. Within the IOC's Harmful Algal Bloom programme, UNESCO is doing just that.

G.M.Hallegraeff[3]

Adapted from the introduction to the Manual on Harmful Marine Microalgae*, published by UNESCO's Intergovernmental Oceanographic Commission in 2003. The manual is used in UNESCO training workshops around the world.*

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Request a subscription to the IOC's newsletter, Harmful Algae News: http://ioc.unesco.org/hab/news.htm; v.bonnet@unesco.org;

To order the Manual*: www.unesco.org/publishing*

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1. *El Niño is caused by an imbalance in atmospheric pressure and sea temperature between the eastern and western parts of the Pacific Ocean.*
2. *Source: Lam and Ho (1989) Red tides in Tolo Harbour, Hong Kong. In:* Red tides: *Biology,* Environmental Science and Toxicology. *Elsevier. Reproduced in UNESCO (2003)* Manual on Harmful Marine Microalgae.
3. *Professor at the School of Plant Science at the University of Tasmania in Australia and Editor-in-Chief of the* Manual on Harmful Marine Microalgae *published by UNESCO in 2003*