CHAPTER 7

Algae and cyanobacteria in coastal and estuarine waters

In coastal and estuarine waters, algae range from single-celled forms to the seaweeds. Cyanobacteria are organisms with some characteristics of bacteria and some of algae. They are similar in size to the unicellular algae and, unlike other bacteria, contain blue-green or green pigments and are able to perform photosynthesis; thus, they are also termed blue-green algae.

Algal blooms in the sea have occurred throughout recorded history but have been increasing during recent decades (Anderson, 1989; Smayda, 1989a; Hallegraeff, 1993). In several areas (e.g., the Baltic and North seas, the Adriatic Sea, Japanese coastal waters and the Gulf of Mexico), algal blooms are a recurring phenomenon. The increased frequency of occurrence has accompanied nutrient enrichment of coastal waters on a global scale (Smayda, 1989b).

Blooms of non-toxic phytoplankton species and mass occurrences of macro-algae can affect the amenity value of recreational waters due to reduced transparency, discoloured water and scum formation. Furthermore, bloom degradation can be accompanied by unpleasant odours, resulting in aesthetic problems (see chapter 9).

Several human diseases have been reported to be associated with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria that occur in the marine environment (CDC, 1997). The effects of these algae on humans are due to some of their constituents, principally algal toxins. Marine algal toxins become a problem primarily because they may concentrate in shellfish and fish that are subsequently eaten by humans (CDR, 1991; Lehane, 2000), causing syndromes known as paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP) and ciguatera fish poisoning (CFP).

Notwithstanding the importance of dietary exposure for humans, this chapter deals only with the possible risks associated with recreational activities in (or near) coastal and estuarine waters. Exposures through dermal contact, inhalation of sea spray aerosols and ingestion of water or algal scums are briefly considered, as are precautionary measures that can be taken. Chapter 8 deals with algae and cyanobacteria in freshwater. More detailed coverage of cyanobacteria and human health is available in *Toxic Cyanobacteria in Water* (Chorus & Bartram, 1999).

7.1 Exposure through dermal contact

Marine cyanobacterial dermatitis ("swimmers' itch" or "seaweed dermatitis") is a severe contact dermatitis (inflammation of the skin) that may occur after swimming in water containing blooms of certain species of marine cyanobacteria. The symptoms are itching and burning within a few minutes to a few hours after swimming in an area where fragments of the cyanobacteria are suspended. Visible dermatitis and redness develop after 3–8 h, followed by blisters and deep desquamation. Some marine beaches, for example, report widespread problems due to a benthic marine cyanobacterium, *Lyngbya majuscula*, which grows on rocks in tropical seas and may cause severe blistering if trapped under the bathing suits of swimmers; this generally happens following storm conditions, which cause the dispersal of the cyanobacterium (Grauer & Arnold, 1961). To date, incidents have been reported only from Japan, Hawaii and Australia (Grauer & Arnold, 1961; WHO, 1984; Yasumoto & Murata, 1993).

Some toxic components, such as aplysiatoxin, debromoaplysiatoxin and lyngbyatoxin A, have been isolated from marine cyanobacteria (Mynderse et al., 1977; Fujiki et al., 1985; Shimizu, 1996). The cyanobacterium *Lyngbya majuscula* is known to produce debromoaplysiatoxin and lyngbyatoxin A, and the cyanobacteria *Oscillatoria nigroviridis* and *Schizothrix calcicola* are known to produce debromoaplysiatoxin (Mynderse et al., 1977). These toxins are highly inflammatory and are potent skin tumour promoting compounds, utilizing mechanisms similar to those of phorbol esters (i.e., through the activation of protein kinase C) (Gorham & Carmichael, 1988; Fujiki et al., 1990). More research is needed to establish the possible tumour promotion risks for human populations.

Occasionally, skin irritation problems have also been reported by swimmers exposed to certain strains of the marine cyanobacterium *Trichodesmium*, as well as dense raphidophyte blooms of *Heterosigma akashiwo* (Falconer, pers. com.).

There is little information on the adverse effects of dermal contact with marine waters containing algal species producing DSP, PSP, ASP and NSP toxins or those species of marine dinoflagellates and flagellates that have been associated with the death of fish and invertebrates. However, people with occupational exposure to waterways (Pocomoke estuary in Maryland, USA) in which toxin-producing *Pfiesteria* or *Pfiesteria*-like dinoflagellates were present were found to be at risk of developing a reversible clinical syndrome characterized by difficulties with learning and higher cognitive function. The risk of illness appeared to be directly related to the degree of exposure (both dermal and exposure to aerosolized spray from the water) (Grattan et al., 1998). CDC (1997) noted that clinical features from exposure to *Pfiesteria piscicida* and related organisms include memory loss, confusion and acute skin burning.

7.2 Exposure through ingestion (of water or scum)

Nodularia spumigena was the first cyanobacterium recognized to cause animal death (Francis, 1878). The toxin produced by *N. spumigena*, called nodularin, is a cyclic pentapeptide. Nodularin is a hepatotoxin, in that it induces massive haemorrhages in the liver of mammals and causes disruption of the liver structure; it also has some effects on the kidneys (Eriksson et al., 1988; Sandström et al., 1990). Nodularin acts by inhibiting serine–threonine protein phosphatases (Fujiki et al., 1996). In the 19th century, several toxic blooms and accumulations of *Nodularia spumigena* were registered. Published literature relates to blooms of *N. spumigena* associated with poisoning of ducks (Kalbe & Tiess, 1964), dogs (Edler et al., 1985; Nehring, 1993), young cattle (Gussmann et al., 1985) and sheep (Main et al., 1977). To date, there have been no reports of human poisoning by *N. spumigena*, but humans may be as susceptible to the toxins as other mammals. Therefore, it is possible that small children, in particular, may accidentally ingest toxic material in quantities with potentially serious consequences.

Other than the study referred to in section 7.1, there is no evidence for adverse effects of ingestion of marine waters containing algal species producing DSP, PSP, ASP and NSP toxins, etc.

Some species of cyanobacteria are capable of causing dense scums, which contain high concentrations of cells. Since most toxin is intracellular, scums caused by toxigenic strains may contain elevated concentrations of toxin. The existence of a cyanobacterial scum caused by a toxigenic species represents an increased human health hazard. Scums are less of a problem in marine water than in fresh water, as the frequency of occurrence of scums is higher in lakes than in coastal areas.

7.3 Exposure through inhalation

Inhalation of a sea spray aerosol containing fragments of marine dinoflagellate cells and/or toxins (e.g., brevetoxins) released into the surf by lysed algae can be harmful to humans (Baden et al., 1984; Scoging, 1991). Brevetoxins are produced by the unarmoured marine dinoflagellate *Gymnodinium breve* (now referred to as *Karenia brevis*). For many years, these blooms were reported only from the south-east USA and eastern Mexico (Steidinger, 1993), but similar problems have now been reported in New Zealand (Fernandez & Cembella, 1995), which were thought to have been caused by *Karenia mikimotoi*. From 1998 to 2001 summer blooms of *Otreopsis ovata* occurred in the Apuan (Tuscany, Italy) benthic seawaters (Sansoni et al., 2002), with major consequences to the benthic flora. In 1998, on the tract of land inland from the bloom-affected area, some 100 people reported symptoms including coughing, sneezing and, in some cases, fever, which were associated with the inhalation of sea spray aerosol.

The signs and symptoms of exposure to brevetoxins by inhalation are severe irritation of conjunctivae and mucus membranes (particularly of the nose) followed by persistent coughing and sneezing and tingling of the lips. The asthma-like effects are not usually observed more than a few kilometres inland (Pierce, 1986).

7.4 Identification of marine toxic algae and cyanobacteria

Detailed information on sampling, identification and cell counts are described in Hallegraeff et al. (2003) for marine toxic phytoplankton and in Chorus & Bartram (1999) for cyanobacteria. Immunoassays are currently the most sensitive and specific methods for rapid screening of samples for microcystins, which are toxins produced by certain cyanobacteria (Ueno et al., 1996), they can also be used for algal toxins. These methods have also been developed for PSP toxins (Cembella et al., 1995), DSP toxins (Levine et al., 1988; Usagawa et al., 1989) as well as ASP and NSP toxins, although in recreational water health effects are not thought to be due to the toxins, but are more likely to be caused by different (largely uncharacterised) compounds, such as lipopolysaccharides.

In most cases, the identification of an algal or cyanobacterial species is not sufficient to establish whether or not it is toxic, because a number of strains with different toxicity may belong to the same species. As a consequence, in order to ascertain whether the identified species includes toxic strains, there is a need to characterize the toxicity. The most commonly employed method is the mouse bioassay, which has been successfully applied in the cases of cyanotoxins (Falconer, 1993), PSP toxins (WHO, 1984), NSP toxins (McFarren et al., 1960) and DSP toxins (Yasumoto et al., 1984). Toxicity is tested by intraperitoneal injection followed by 24-hour observation. This method is not specific but within a few hours provides a measure of the total toxicity. The mouse assay is not sensitive enough for testing ASP toxins. Many analytical methods based on high-performance liquid chromatography are now available to determine the occurrence of cyanotoxins (Lawton et al., 1994; Chorus & Bartram, 1999) as well as specific ASP (Lawrence et al., 1989), DSP (Lee et al., 1987), NSP (Pierce et al., 1985) and PSP (Sullivan & Wekell, 1987) toxins.

7.5 Guideline values

Available data indicate that the risk for human health associated with the occurrence of marine toxic algae or cyanobacteria during recreational activities is limited to a few species and geographical areas. As a result, it is inappropriate to recommend specific guideline values, although authorities should be aware of the potential hazard and act accordingly.

7.6 Precautionary measures

7.6.1 Monitoring

Within areas subject to the occurrence of marine toxic algae or cyanobacteria, it is important to carry out adequate monitoring activities and give information to the human population potentially affected. Monitoring programmes should be planned with the aim of preventing human exposure in areas affected by blooms of toxic algae or cyanobacteria. In some cases, satellite imagery can be used as a part of a proactive monitoring programme. For example, movements of the Gulf Stream and subsequent elevated water temperatures play a key role in *Gymnodinium breve* blooms; Gulf Stream temperatures monitored by remote sensing of infrared radiation can provide information on the likelihood of a bloom and its subsequent movement (Hungerford & Wekell, 1993).

Long data records on phytoplankton populations, toxic and otherwise, may contribute to a more comprehensive understanding of phytoplankton dynamics and ecosystem function, which could lead to more efficient monitoring. If, for instance, long time series of data concerning phytoplankton populations exist, it would be possible to decide if a species that has suddenly appeared is new to the area or if endemic species have become toxic. Important supporting parameters include temperature, salinity, chlorophyll (phytoplankton biomass) and surface current circulation (transport of harmful algae). Knowledge of the temporal and geographic distribution of inorganic nutrients and their sources, as well as other phytoplankton growth factors, are also important when planning and operating a monitoring programme (Andersen, 1996).

When conditions favourable to algal or cyanobacterial blooms are recognized, monitoring activities should be intensified and should include taxonomic ranking of potentially toxic species and eventually analysis of the algal toxins (Hallegraeff et al., 2003).

7.6.2 Information

In affected areas, it is appropriate to provide general practitioners and medical clinics with information regarding the health problems potentially associated with algal blooms and toxic algae, the diagnosis and treatment of poisonings, the surveillance of groups of people who could be at risk and procedures for reporting to public health authorities. Health information should also be made available to the general public and to recreational water users in particular. Information may be disseminated through various means, including schools, on-site notices, mass media and specific brochures. These should contain information about algal blooms and toxic algae, the possible health effects, reporting procedures for any health problems thought to be possibly linked with water-based recreation and recommended protective measures.

As a precaution, the following guidance is recommended for potentially affected areas and should be included in public information:

- Avoid areas with visible algal concentrations and/or algal scums in the sea as well as on the shore. Direct contact and swallowing appreciable amounts are associated with the highest health risk.
- On the beach, avoid sitting downwind of any algal material drying on the shore, which could form an aerosol and be inhaled (particularly in areas with *Gymnodinium breve* blooms).
- If sailing, windsurfing or undertaking any other activity likely to involve water immersion in the presence of algal blooms, wear clothing that is close fitting in the openings. The use of wet suits for water sports may result in a greater risk of rashes, because algal material in the water trapped inside the wet suit will be in contact with the skin for long periods of time.
- After coming ashore, shower or wash yourself down to remove any algal material.
- Wash and dry all clothing and equipment after any contact with algal blooms and scum.
- If any health effects are subsequently experienced and whatever the nature of the exposure, seek medical advice.

In some areas, information on harmful algal blooms is distributed rapidly to users of the monitoring system by telephone, telephone answering machine, fax, E-mail and/or Internet (e.g., the Baltic Sea Alg@line, found at http://www2.fimr.fi/project/algaline/algaetu.htm) (Andersen, 1996).

7.6.3 Prevention of marine algal blooms

There have been several attempts to develop practical methods for controlling algal blooms. The use of clays, herbicides, metals, chelators, artificial turbulence, dinoflagellate parasites and zooplankton all have been the subject of research. Unfortunately, many of these methods are not practical and may have adverse ecological side-effects.

Algal blooms result from a complex interaction between hydrographic, meteorological, biological and chemical conditions, of which only a few can be controlled. Without essential nutrients, principally nitrates and phosphates, algae will usually not reach bloom proportions. Excessive nutrient input from land-based sources is one of the most influential promoting factors, and minimization of nutrient availability will often contribute to controlling algal growth.

7.7 References

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