6

Coastal and marine phytoplankton: diversity and ecology

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6.1 Marine phytoplankton: diversity and ecology

Phytoplankton (*phyto = plant, planktos* = made to wander) consist of microscopic algae, cyanobacteria (blue-green algae) and other protists that live suspended in the water. With tens of thousands of species identified in coastal and oceanic waters, microalgae are highly diverse, yet largely underexplored, with up to nine major functional groups (having similar ecological or biogeochemical roles). Most phytoplankton are unicellular and range in size from 0.2 to 200 µm, with a few taxa attaining up to 2 mm in length. Many phytoplankton species are autotrophic and produce energy for growth and reproduction through photosynthesis, by fixing carbon and converting it to chemical energy. Carbon fixed by photosynthesis is termed 'primary production', which uses sunlight, atmospheric carbon dioxide and dissolved nutrients such as nitrate and phosphate to provide energy. Calcium or silicate is used for development of the structure of the cell in some species. A by-product of this process is the generation of oxygen, and approximately half of the oxygen in the atmosphere is produced by phytoplankton. Although the majority of the phytoplankton are autotrophic (i.e. 'self-feeding'), some are heterotrophic where cells depend on the uptake of organic material from their environment, by ingesting other cells and particles, or by taking in soluble material (Horner 2002). Other species are mixotrophic (combining autotrophic and heterotrophic modes), and symbiotic relationships of photosynthetic cells with many tiny bacteria and cyanobacteria abound. Either way, phytoplankton form the foundation of the marine food web, providing nutrition either directly or indirectly to higher trophic levels, including important fisheries and ourselves.

Pigments are chemical compounds contained in the chloroplasts of microalgae that assist in capturing solar energy for photosynthesis. In order to acquire more of the sun's energy, different phytoplankton produce several different kinds of pigments to absorb a broader range of wavelengths. As well as distinguishing between the major functional groups, pigments reflect evolutionary relationships between these groups and provide us with a method of measuring phytoplankton biomass and determining production rates (growth) of different phytoplankton communities.

In the following sections we will discuss the major functional groups of phytoplankton found in temperate coastal waters and give a brief description of each group:

- Bacillariophyta (diatoms) (Section 6.2)
- Dinoflagellata (dinoflagellates) (Section 6.3)
- Cyanobacteria (blue-green algae) (Section 6.4)
- Other marine phytoplankton (Section 6.5)

- Raphidophyceae (raphidophytes)
- Dictyochophyceae (silicoflagellates)
- Prymnesiophyceae = Haptophyta (coccolithophorids, prymnesiophytes, golden brown flagellates)
- Cryptophyceae (cryptomonads)
- Euglenophyceae (euglenids)
- Chlorophyceae (green algae – prasinophytes, chlorophytes)

Phytoplankton are classified into these functional or taxonomic groups based on a combination of their photosynthetic pigments, as well as other characteristics such as the way in which they store energy (lipid or carbohydrate) and the structure of their cell walls. Other distinguishing features include the presence or absence of flagella, the structure of the flagella or flagella roots, the pattern and course of mitosis (cellular division) and cytokensis (cell division) or other morphological attributes such as symmetry and size.

Many of these groups are represented in the microplankton (20–200 µm), the nanoplankton (2–20 µm) and the picoplankton (0.2–2 µm) – with some occurring in all three-size classes. In temperate coastal waters, the nanoplankton can account for 80% of the total phytoplankton biomass, while in tropical waters the picoplankton can account for 80% of the total phytoplankton biomass. Green flagellates, small non-thecate dinoflagellates, cryptomonads, prymnesiophytes, coccolithophorids and other colourless flagellates are all common representatives of the nanoplankton in coastal waters. Picoplankton are represented by the cyanobacteria and chrysophytes.

6.2 Bacillariophyta (diatoms)

Diatoms are abundant single-celled phytoplankton containing membrane-bound cell organelles, with around 15 000 species described in fresh waters (Section 5.4) and marine waters. They are distinguished from other groups by two highly ornamented siliceous plates or valves (sometimes termed theca or frustules) that enclose the protoplast, with the hypotheca slightly smaller and fitting inside the epitheca. They may occur as solitary cells or in stunning beautiful colonial or chain forms, linked by siliceous structures such as setae or spines, or by mucilage threads of a sugary polysaccharide secreted through specialised structures. The structure, patterns and processes of the cell wall, but more importantly, valve symmetry, form the basis for the two major groups within the diatoms: the pennate and the centric diatoms. Pennate diatoms are elongate and usually bilaterally symmetrical, with up to 800 marine species identified. Centric diatoms are usually round or 'radially symmetrical' (with the frustule often compared to a Petri dish or pillbox) and there are up to ~1000 species in marine waters (Fig. 6.1).

Diatoms, unlike nearly all other phytoplankton, have no flagella and are in most cases non-motile. Pennate forms can achieve a gliding motion via mucilage secretion through their raphe system (a longitudinal slit in the valve), while centric diatoms can exude mucilage through their labiate processes (tubes or openings through the valve wall), allowing limited movement. Diatoms tend to sink because of their density, relying on the turbulence of marine systems to keep them suspended in the sunlit upper layers of the ocean where they can photosynthesise, but recent studies have shown that they are able to control the rate of sinking to optimise nutrient exchange.

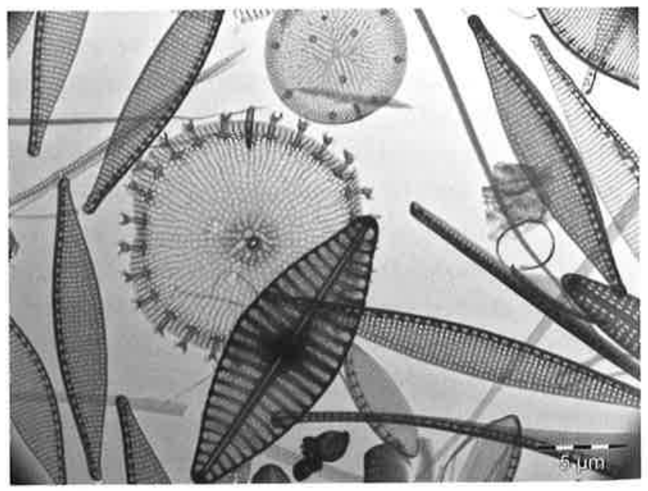

Fig. 6.1. Transmission electron microscopy of common diatom species found in temperate coastal waters of New South Wales, Australia. Both centric (radially symmetrical) and pennate (bilaterally symmetrical) forms can be seen (photo: P. Ajani).

Diatoms may also be benthic: living in or growing on sediments, rocks and larger plants (Box 6.1). In coastal waters, limiting factors – such as silicate (and other nutrient) availability, water stability, light climate, parasitism and grazing – affect which species are present in the water column at particular times. Diatom blooms often occur in coastal waters when episodic upwelling brings nutrient-rich water to the surface, where there is better access to light and subsequent increased production (Box 6.2).

Some diatom blooms can become so dense that they can kill fish and invertebrates due to either oxygen depletion or by abrasion damage to their gills (such as *Thalassiosira* spp. and *Chaetoceros* spp.). Certain diatom species belonging to the genera *Pseudo-nitzschia* and *Nitzschia* produce the potent neurotoxin domoic acid and are implicated as causing amnesic shellfish poisoning (ASP) (Box 6.3).

Diatom frustules have a slow rate of decay, which has resulted in massive geological deposits known as diatomaceous earth. This material is used in filtration, cosmetics, toothpaste and even forensic science. Diatoms also present an important record of past environmental conditions, through accumulation of their silica-based frustules in ocean sediments.

Box 6.1 Benthic phytoplankton

Benthic phytoplankton or microphytobenthos (MPB) are important communities in terms of estuarine and coastal ecology. MPB assemblages play a central role in the production and cycling of organic matter in these environments, as well as stabilising sediments by excreting mucilaginous substances into the sediment and thus preventing erosion. Microphytobenthos assemblages usually include bacteria, flagellates, ciliates, diatoms, dinoflagellates and other algae, as well as foraminifers and nematodes. Further groupings can be found within the diatoms – some live freely on (epipelic) or in the sediments (endopelic). Those living attached to the substratum are classified according to their substrata preference: sand grains (epipsammic), rock or stones (epilithic), plants (epiphytic) and epizoic (animals).

Although phytoplankton communities in coastal waters have received much attention, very few studies have been carried out on the MPB communities. This is probably because of the difficulties in extracting and enumerating the cells from the sediments. The few studies that have been carried out in our coastal waters list the abundant MPB genera as the diatoms *Amphora, Cocconeis, Bacillaria, Navicula, Nitzchia, Gyrosigma, Mastogloia,* and *Pleurosigma* (Saunders *et al.* 2010) as well as the dinoflagellates *Amphidinium, Prorocentrum Amphidiniopsis, Ostreopsis, Gambierdiscus* and *Gyrodinium* (Hallegraeff *et al.* 2010). Green euglenids, such as *Eutreptia*, are also common.

Box 6.2 Diatom blooms

Seasonal signals in phytoplankton biomass along the east coast of Australia coincide with intermittent slope water intrusions bringing cold, nutrient-rich water into the euphotic zone (Ajani *et al.* 2001b). In addition to these sporadic upwelling/downwelling events, a distinct seasonal cycle in phytoplankton community composition has been observed with species richness peaking in the winter. The spring and summer blooms are characterised by a clear successional pattern, beginning with small diatoms, such as *Asterionellopsis, Thalassiosira, Skeletonema, Pseudo-nitzschia* and *Chaetoceros*, followed by larger diatoms, such as *Ditylum, Leptocylindrus, Eucampia, Rhizosolenia, Melosira* and *Thalassiothrix*, and concluding with dinoflagellates, most notably species of the genera *Tripos* and *Protoperidinium*

6.3 Dinoflagellata (dinoflagellates)

Dinoflagellates are a group of unicellular algae with membrane bound organelles (and therefore eukaryotes) and two flagella. There are ~2000 living species known (130 genera, Fig. 6.2; see Section 5.5 for freshwater species). About half the dinoflagellates feed on organic matter only (i.e. they are heterotrophs, including some carnivores) and the other half either photosynthesise or are partly autotrophic and partly heterotrophic.

Box 6.3 Species belonging to the *Pseudo-nitzschia* genus

Pseudo-nitzschia is a pennate diatom genus with a global marine distribution. Of the 49 species described to date worldwide, 26 have been found to produce domoic acid (DA): a potent neurotoxin that can accumulate in the marine food web and cause both ecosystem and human health effects such as amnesic shellfish poisoning (ASP) (https://en.wikipedia.org/wiki/Pseudo-nitzschia). For this reason, the routine monitoring of *Pseudo-nitzschia* cell densities and the concentration of the toxic compound DA is the focus of many seafood safety programs globally.

Species belonging to the genus *Pseudo-nitzschia* are a significant component of the phytoplankton community in Australian waters (Hallegraeff 1994, Ajani *et al.* 2013a,b; 2016a). To date, only three species of *Pseudo-nitzschia* have been found to produce DA: *P. australis, P. cuspidata* and *P. multistriata*. *Pseudo-nitzchia cuspidata* was responsible for a significant toxic bloom in south-eastern Australia in 2010, where maximum cell densities of $>6 \times 10^6$ cells/L and DA in oyster tissue of 34 mg DA/kg were reported (Ajani *et al.* 2013b).

Toxic *Pseudo-nitzschia* blooms are also a common reoccurrence along the west coast of North America. A major bloom occurring in 2015–2016 was caused by anomalous ocean conditions and resulted in high levels of domoic acid in the food web (McCabe *et al.* 2016). While a sophisticated harmful algal bloom monitoring program and response network meant that no human illnesses were reported, there were significant impacts to commercial and recreational fisheries.

Dinoflagellates are motile at some stage of the life cycle – having two different flagella. One flagellum is situated in a girdle groove around the middle of the cell (for rotation) and the other projects from the sulcus groove (at one end) for propulsion. Careful use of a microscope is required to see these flagella. Dinoflagellates may be armoured (thecate – with cellulose cell walls made of plates) or unarmoured (non-thecate or naked). Armoured dinoflagellates are usually irregular in shape, bearing horns, ridges and wings, which aid in identification.

Over 80 species of marine dinoflagellates produce cysts and at least 16 of these species are known to cause red tides and seven species to be toxic. Cysts can be of two types: either temporary cysts (whereby the cell quickly re-established itself after a brief encystment) or resting cysts, which sink from the water column and often remain in the sediment anywhere from 6 weeks to many years, depending on the species. The purpose of cyst formation is probably a survival strategy, which is regulated by both physiological and environmental factors such as:

- protection from adverse conditions (such as temperature or nutrient availability)
- a refuge from predation
- alternation between planktonic and benthic habitats
- as part of the reproductive process
- aid in dispersion/seed population for the subsequent bloom.

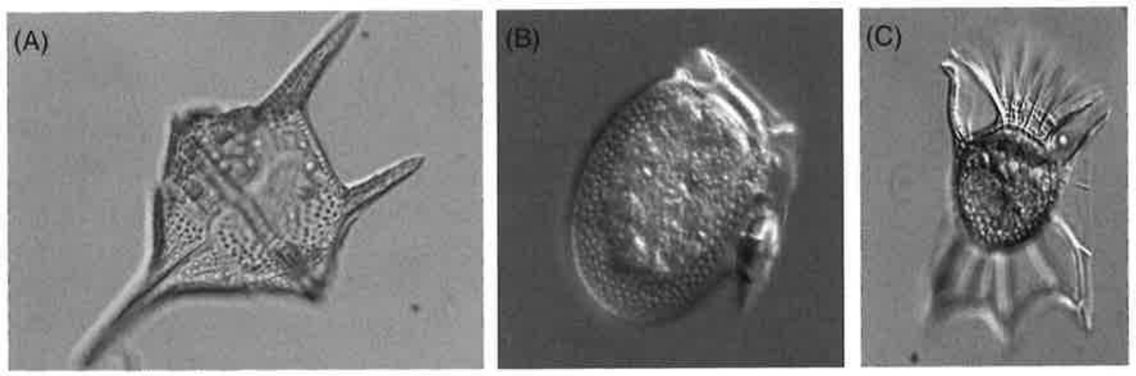

Fig. 6.2. Light microscopy images of some common dinoflagellate species found in temperate coastal waters of New South Wales, Australia: **(A)** *Ceratium pentagonum*; **(B)** *Dinophysis acuminata*; and **(C)** *Ornithocerus magnificus* (photos: P. Ajani).

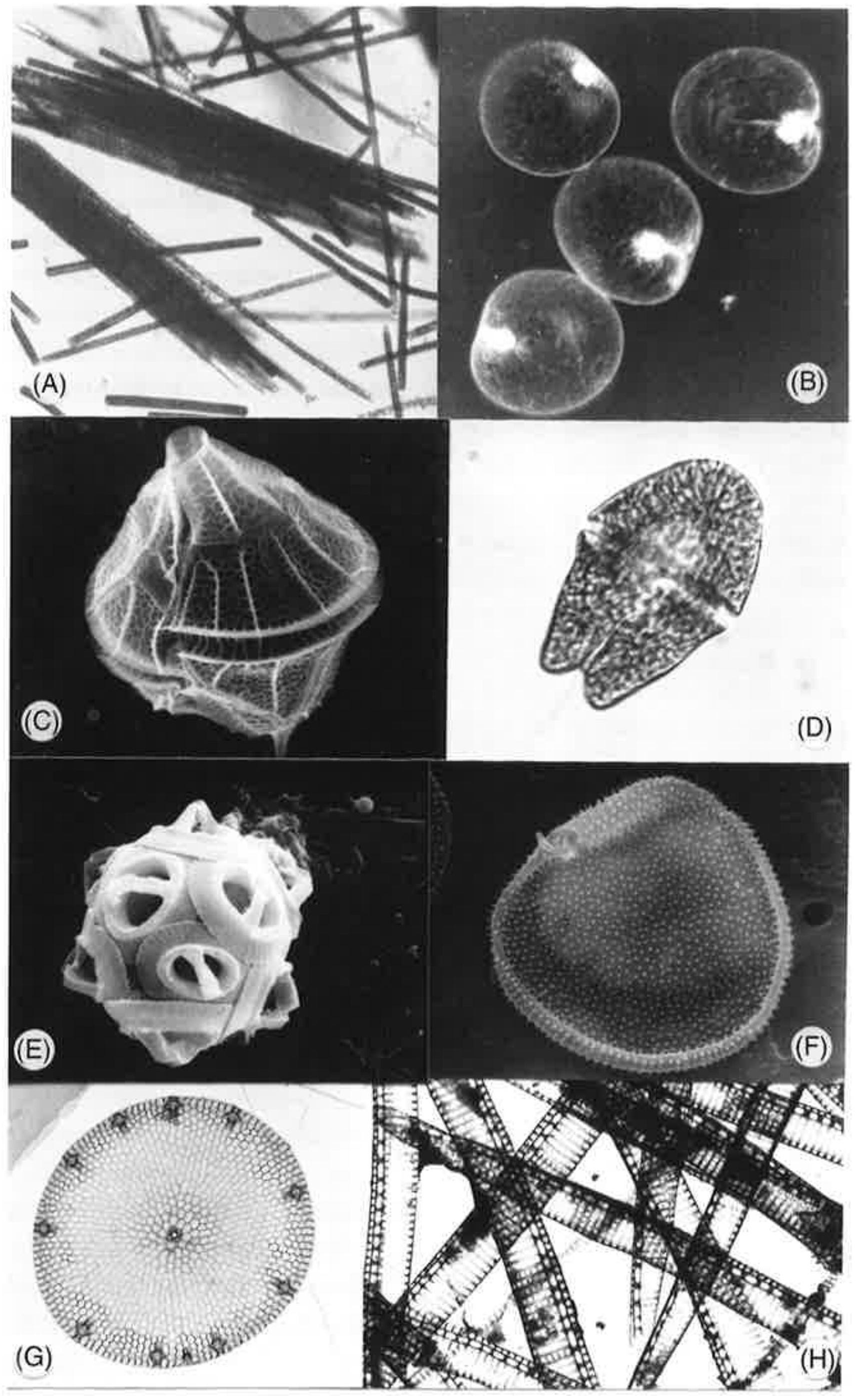

Fig. 6.3. Common bloom species in New South Wales marine and estuarine waters: **(A)** light microscopy (LM) of the filamentous cyanobacterium *Trichodesmium erythraeum* producing raft-like bundles, up to 750 µm long; **(B)** LM of the balloon-shaped, colourless dinoflagellate *Noctiluca scintillans*, 200–500 µm diameter; **(C)** scanning electron microscopy (SEM) of the dinoflagellate *Gonyaulax polygramma*, showing ornamented cellulose plates with longitudinal ridges, 29–66 µm long; **(D)** LM of the large, unarmoured dinoflagellate *Akashiwo sanguinea*, 50–80 mm long; **(E)** SEM of the calcareous nanoplankton *Gephyrocapsa oceanica*, 15 µm diameter; **(F)** SEM of the triangular, armoured dinoflagellate cells of *Prorocentrum cordatum*, 10–15 µm wide and covered with minute spinules; **(G)** transmission electron microscopy (TEM) of the weakly silicified cell of the centric diatom *Thalassiosira partheneia*, 10 µm diameter; **(H)** TEM of a bloom of the pennate diatom *Pseudo-nitzschia pseudodelicatissima*, 57–150 µm long (photos courtesy of Ajani *et al.* 2001a).

Many dinoflagellates make daily diurnal migrations up and down the water column. During the day, they migrate towards the surface of the water (for better light availability) and at night, they move down to a depth of several metres (for better access to nutrients). This vertical migration is an important consideration when sampling or when analysing the results of sampling activities.

A regularly occurring red tide on the south-east Australian coast is caused by the dinoflagellate *Noctiluca scintillans* (Fig. 6.3B) (Ajani *et al.* 2001a). *Noctiluca* are large (up to 1 mm diameter) balloon-shaped, heterotrophic dinoflagellates that consume other algae, some zooplankton and even fish eggs. They have no photosynthetic pigments, although in tropical waters they may appear green due to endosymbiotic, green-pigmented prasinophytes living in their vacuoles. *Noctiluca* are positively buoyant (due to ammonia production) causing dense red slicks to form in surface waters. As blooms die off the ammonia is released into the environment, which is potentially dangerous to fish. *Noctiluca* are bioluminescent at night (i.e. they glow), especially around a moving boat or breaking wave. Interestingly, the frequency of this species off south-eastern Australia has increased in recent years. Using continuous plankton recorder data, McLeod *et al.* (2012) reported on the climate-driven range expansion of this species into the Southern Ocean. This species appeared to be transported south by an East Australian Current warm-core eddy, most likely because of the increased poleward penetration of this western boundary current.

Dinoflagellates have the largest number of known harmful species (around 40 species), with new discoveries still being made. Similar to diatoms, they can produce toxic compounds that accumulate in filter-feeding bivalves and the larvae of commercially important crustaceans and finfish. Consumption of these seafoods by humans can result in a range of symptoms including gastroenteritis, headaches, muscle and joint pain. In extreme cases, paralysis and respiratory failure can occur, caused by several major poisoning syndromes: paralytic shellfish poisoning (PSP); diarrhetic shellfish poisoning (DSP) (Box 6.4); neurotoxic shellfish poisoning (NSP); azaspiracid shellfish poisoning (AZP); and ciguatera fish poisoning (CFP). On a global scale, ~60 000 human intoxications occur per year worldwide, with an overall mortality of ~1.5% (Kantiani *et al.* 2010).

Box 6.4 Species belonging to the *Dinophysis* genus

Even at very low cell densities (<10^3 cells/L), species belonging to the dinoflagellate genus *Dinophysis* can produce phycotoxins that cause diarrhetic shellfish poisoning (DSP), a type of gastroenteritis in consumers of seafood. *Dinophysis* is widespread in Australian waters, with 36 species reported thus far. Toxic representatives include *D. acuminata, D. acuta, D. caudata, D. fortii* and *D. hastata*. There have been three major DSP events in Australia to date. In 1997 *D. acuminata* and *D. tripos* were implicated in the contamination of pipis (*Plebidonax deltoides*) in New South Wales (NSW) in which 102 people were affected, and 56 cases of gastroenteritis reported. In March 1998 a second outbreak was reported in which 20 cases of DSP poisoning were reported. In March 2000, a third outbreak occurred in Queensland and was again linked to the consumption of pipis, when only one person was affected.

Dinophysis species are common in Australian coastal waters, but rarely abundant. Although the highest abundance of *D. acuminata* has been observed in spring in the Hawkesbury River estuary (maximum abundance 4500 cells/L), the highest abundance of *D. caudata* was in summer to autumn (maximum 12 000 cells/L), highlighting the species-specific seasonality of this toxic group.

Being a cosmopolitan genus, 'diarrhetic shellfish poisoning' caused by *Dinophysis* occurs in many parts of the world (Ajani *et al.* 2016b and references therein) so this genus is the focus of many harmful algal monitoring programs.

6.4 Cyanobacteria (blue-green algae)

Cyanobacteria are primitive algae characterised by the absence of membrane-bound cell components

(i.e. they are prokaryotes; see also Section 5.2). Cyanobacteria are often blue-green in colour. They have unicellular, colonial and filamentous forms, and do not have flagellate cells at any stage in their life cycle.

Cyanobacteria include benthic and planktonic forms. Many species have adaptations to aid survival in extreme and diverse habitats, such as gas vacuoles for buoyancy control, akinetes (resting stages) and heterocysts (specialised cells that can fix atmospheric nitrogen) for survival in waters where the nitrate and ammonia levels are relatively low. Not all taxa have these features. In marine and brackish waters, cyanobacteria have produced toxins that have resulted in neuromuscular and organs distress as well as external contact irritation.

Six genera of cyanobacteria have been implicated in blooms in Australian coastal waters: *Dolichospernum, Microcystis, Amphizomenon, Nodularia, Trichodesmium* and *Lyngbya*, several which produce phycotoxins (see Chapter 3). *Trichodesmium* is a most common cyanobacterium in most waters worldwide, and is able to 'fix' atmospheric nitrogen into nitrate (i.e. a diazotroph) and therefore important in tropical marine ecosystems. This tropical/subtropical species produces episodic 'red tides' that were historically reported as 'sea sawdust' during Captain Cook's voyage through the Coral Sea in 1778. The filaments of this cyanobacterium are united (parallel) into small raft-like bundles that are just visible to the naked eye (around 1 mm). The filaments are generally cylindrical, uniformly broad or slightly tapering at the tips, and are straight or slightly curved. *Trichodesmium* filaments do not have any specialised cells such as heterocysts or akinetes (Fig. 6.3A).

Blooms of *Trichodesmium* have been linked to respiratory distress and contact dermatitis in humans, as well as toxicity in zooplankton and higher trophic levels in coral reef and tropical environments (Golubic *et al.* 2010). Blooms of *Trichodesmium* are most commonly seen in subtropical and tropical waters most commonly around northern Australia and the Red Sea. They occur in northern NSW waters in spring, summer and early autumn when the East Australian Current (EAC) transports these algal masses into NSW from Queensland waters. These blooms appear yellow-grey in their early stages, while they become a reddish-brown later.

6.5 Other marine phytoplankton

6.5.1 Raphidophyceae (raphidophytes)

Raphidophytes are unicellular flagellates that have two unequal, heterodynamic flagella arising from a sub-apical shallow groove. The forward-directed flagellum has two rows of fine hairs, while the trailing flagellum is smooth and lies close to the surface of the cells. Their cells are unarmoured, dorsoventrally flattened (potato-shaped) and contain numerous ejectosomes, trichocysts and/or mucocysts that readily discharge upon stimulation. They have a characteristic 'raspberry-like' appearance upon preservation, which can make identification difficult (Fig. 6.4E). Many raphidophytes can be toxic to fish and bloom events have been reported throughout the world in coastal and estuarine waters (Box 6.5). *Heterosigma, Chattonella* and *Fibrocapsa* commonly bloom in summer. Toxic species in this group are a particular concern for aquaculture, where large-scale fish kills may occur due to the inability of caged fish to escape from deteriorating conditions.

Box 6.5 Toxic raphidiophyte blooms

A toxic raphidiophyte, *Chattonella* cf. *globosa*, bloomed sporadically in Sydney Harbour, Australia on a few occasions. Blooms of related species have caused significant mortality of cultured yellowtail and red sea bream in Japanese inland seas and implicated in the mass mortality of farmed blue-fin tuna in South Australia (Marshall and Hallegraeff 1999 and references therein). The production of superoxide radicals as the major mechanism of fish mortality is also hypothesised for this genus. Evidence for brevetoxin-like production is still being investigated.

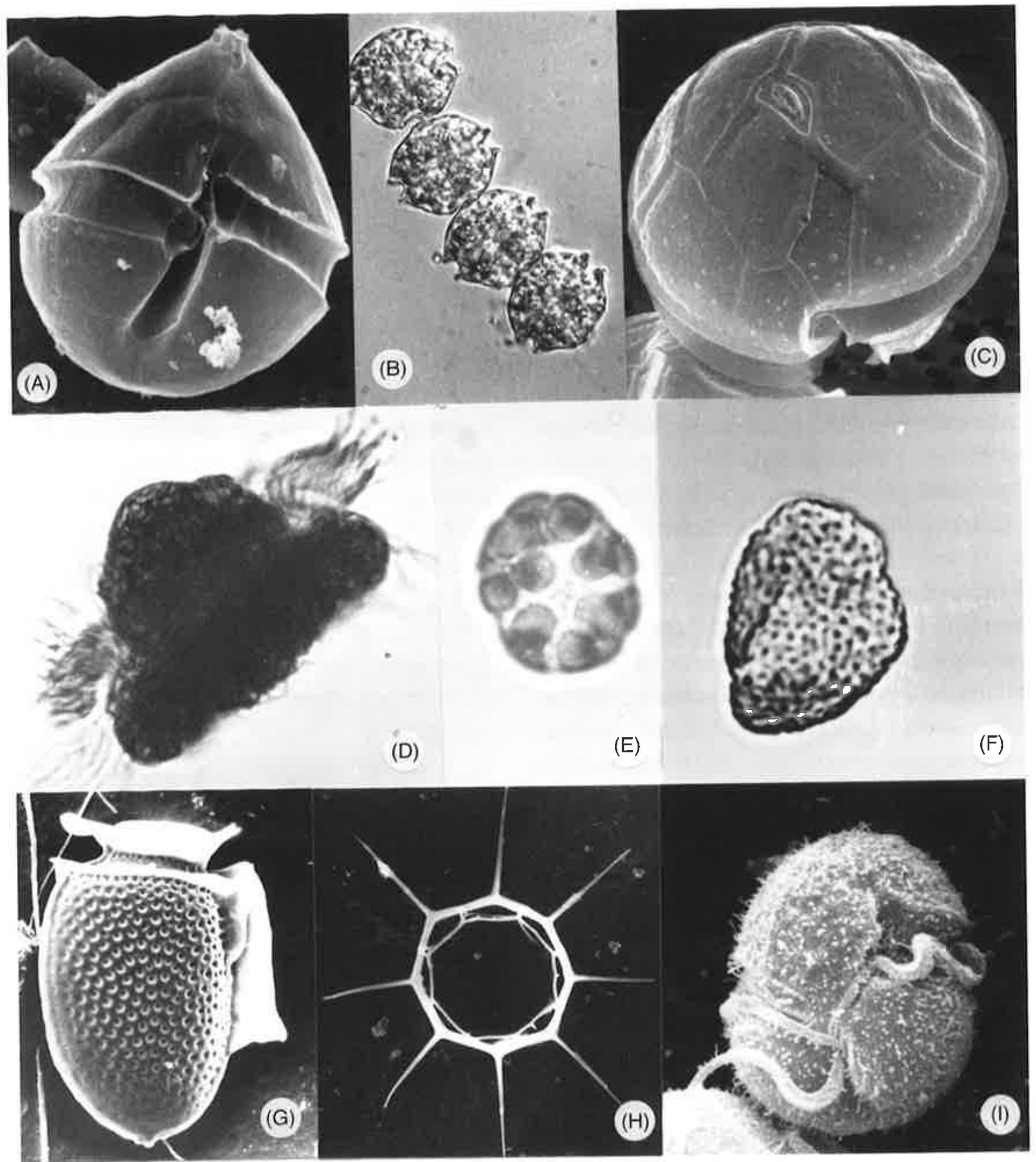

Fig. 6.4. Common bloom species in marine and estuarine waters of eastern Australia: **(A)** scanning electron microscopy (SEM) of the red-water dinoflagellate *Scripsiella trochoidea*, 16–36 µm long. Note tube-shaped apical pore on top of the cell and nearly equatorial (not displaced) girdle groove; **(B)** light microscopy (LM) of the chain-forming dinoflagellate *Alexandrium catenella* – the causative organism of paralytic shellfish poisoning. Individual cells 20–22 µm long; **(C)** SEM of the red water dinoflagellate *Alexandrium minutum* – the causative organism of paralytic shellfish poisoning. Individual cells 24–29 µm diameter. Note the hook-shaped apical pore on top of the cell and characteristic shape of the first apical plate; **(D)** LM of the ciliate *Mesodinium rubrum*, with two systems of cilia arising from the waist region, 30 µm diameter; **(E)** LM of the 'raspberry-like' cell of the fish-killing flagellate *Hetersosigma akashiwo* ('Akashiwo' = red tide), containing numerous disc-shaped chloroplasts, cell 11–25 µm long; **(F)** LM of an undescribed flagellate resembling *Haramonas*. The cell surface is covered by numerous mucus-producing vesicles, cells 30–40 µm long; **(G)** SEM of the small armoured dinoflagellate *Dinophysis acuminata* – the causative organism of diarrhetic shellfish poisoning, cells 38–58 µm long; **(H)** SEM of the siliceous skeleton of the silicoflagellate *Octactis octonaria*, 10–12 µm diameter; **(I)** SEM of the small unarmoured, fish-killing dinoflagellate *Karlodinium micrum*, 15 µm diameter (photos courtesy of Ajani *et al.* 2001a).

6.5.2 Dictyochophyceae (silicoflagellates)

Silicoflagellates are unicellular cells with a single flagellum and a life-cycle that includes a siliceous skeleton. Identification to species level is based on the shape of this silica skeleton. *Octactis* (formerly *Dictyocha*) is the most common genus found in our waters and is perhaps toxic to fish (Box 6.6). In addition to diatoms, these silica skeletons can provide detailed information on past environmental conditions through analysis of their accumulation patterns in sediments.

6.5.3 Prymnesiophyceae = Haptophyta (coccolithophorids, prymnesiophytes, golden brown flagellates)

Prymnesiophytes, also known as haptophytes, are either unicellular or colony-forming flagellates that have two equal or unequal flagella, as well as a 'third flagellum' – a haptonema – a thin filamentous organelle sometimes used for anchoring the cell and sometimes in food uptake. Most species are small and belong to the nanoplankton (2–20 µm). The cell surface is covered with tiny scales or granules of organic material (cellulose), which is used extensively in taxonomy but requires powerful techniques such as scanning electron microscopy for definitive identification (Fig. 6.5). In addition, there may be spectacular calcified scales called coccoliths, which are characteristic of the coccolithophorids (Box 6.7). Coccolithophorids have formed geological deposits, such as the White Cliffs of Dover in the UK, yet are vulnerable to future ocean acidification by virtue of their calcifying scales.

Box 6.6 Silicoflagellate blooms

A silicoflagellate, *Octactis octonaria* (Fig. 6.4H), was implicated as the causative organism in a fish kill that occurred in waters off the coastal city of Newcastle, Australia. Dead fish (especially trevally, *Caranx* sp.) were seen on beaches and floating up to 3 km offshore. While silicoflagellates are regularly seen in these waters in the spring and summer months (Ajani *et al.* 2001a), a bloom event of this magnitude had never previously been recorded in these waters (Hallegraeff 1991).

6.5.4 Cryptophyceae (cryptomonads)

Cryptomonads are very small, ovoid phytoplankton (6–20 µm) with a rigid protein coat and two flagella protruding from a 'gullet' at one end (two equal or unequal in length, with one or two rows of tubular hairs).

6.5.5 Euglenophyceae (euglenids)

Euglenids (or euglenoids) are large (15–500 µm), green, single-celled flagellates that have a deep fold or gullet where the flagellum is attached. The cell has a spiral construction and is surrounded by a pellicle that is composed of proteinaceous

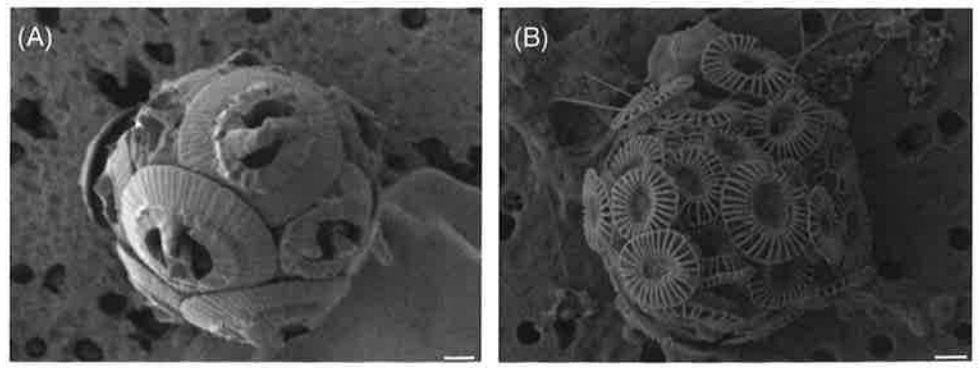

Fig. 6.5. Scanning electron micrograph showing the 'coccoliths' or scales covering the haptophytes: **(A)** *Gephyrocapsa* sp. and **(B)** *Emiliania huxleyi*, both from the Southern Ocean (photos: Ruth Eriksen, courtesy of Australian Antarctic Division Electron Microscopy Unit © Commonwealth of Australia). Scale bar 1 µm.

Box 6.7 Blooms of prymnesiophytes and coccolithophorids

One prymnesiophyte (*Phaeocystis*) is the cause of extensive mounds of sea foam 1–2 m deep around the coasts of the north Atlantic, and the east coast of Australia, usually occurring after blooms coincide with major storms. An unprecedented, bloom of the small (<10 μm) cosmopolitan coccolithophorid *Gephyrocapsa oceanica* (Fig. 6.3E) occurred for 4 weeks in Jervis Bay on the south east Australian coast (Blackburn and Cresswell 1993). The bloom turned the waters milky green, which caused economic hardship for SCUBA diving businesses during the peak tourist season. Upwelling of cool nutrient-rich slope water and an influx of warm East Australian Current waters from an adjacent eddy may have enhanced the nutrients and upper layer temperatures. The maximum cell density of 2×10^7 cells/L was greater than any previously recorded of this species in Australian waters.

interlocking strips that wind helically around the cell (giving the cells a striped pattern). A conspicuous eyespot located in the cytoplasm can also usually be seen. Most of the Euglenophyta are freshwater species (Section 5.6), with only a few marine species reported – mainly belonging to the genera *Eutreptiella*.

6.5.6 Chlorophyceae (green algae – prasinophytes, chlorophytes)

The chlorophytes (green flagellate algae) and the prasinophytes (scaly green flagellate algae) are the two main groups of the Chlorophyceae represented in coastal waters. The prasinophytes are generally small flagellates that are covered in organic scales. From one up to 16 flagella (covered in minute scales and simple hairs) may be present and are used in many species to produce the characteristic stop and start swimming movement. The presence or absence and number of layers of scales covering the cell are used in the taxonomy of the group:

- scales absent (*Micromonas*)
- one layer of scales (*Mantoniella*)
- two or three layers (*Pyramimonas*)
- fused scales (*Tetraselmis*).

The chlorophytes represent a great variety of levels of organisation and include the macroalgae such as *Ulva* (sea lettuce), *Enteromorpha*, *Cladophora* and *Caulerpa*. Marine microalgae are mainly represented by the genera *Dunaliella* and *Chlamydomonas*. These phytoplankton are distinguished by their bright green appearance, flagella and naked cell wall.

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6.7 Further reading

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