Pigments The pigments, which provide the actual colour to the thallus, are some definite chemical compounds. These constitute one of the most effective criteria in algal taxonomy. Each algal class or division has its own particular combination of pigments as shown in Table 5.1.

In algae, four different kinds of pigments (chlorophylls, carotenes, xanthophylls and phycobilins) are found. Round (1973) recognized 5 chlorophylls, 5 carotenes, 20 xanthophylls and 6 phycobilins in algae.

Table 5.1 Principal Pigments of Major Classes

S. No	Class	Pigments			
		Chlorophyll	**Carotene**	**Xanthophyll**	**Phycobilins**
1.	Chlorophyceae	*Chlorophyll-a* Chlorophyll-b	α-, β- and γ *Carotenes*, e-carotene (?); euglenarhodone* (in some)	*Lutein*, zeaxanthin, violaxanthin, neoxanthin, astaxanthin*,** siphonein*, siphonoxanthin*, cryptoxanthin*	Not reported
2.	Xanthophyceae	*Chlorophyll-a* Chlorophyll-e Chlorophyll-c	*β-Carotene*, α-carotene*, e-carotene*	Lutein, violaxanthin, neoxanthin, fucoxanthin, flavacin*, flavoxanthin*	Not reported
3.	Chrysophyceae	*Chlorophyll-a* Chlorophyll-c Chlorophyll-d* Chlorophyll-e*,**	*β-Carotene*, e-carotene*, α-carotene†,†	Lutein, fucoxanthin,† neofucoxanthin, diadinoxanthin, flavacin*, zeaxanthin*, violaxanthin*, flavoxanthin*, neoxanthin*, diatoxanthin*, dinoxanthin*, neodianoxanthin*, peridinin*, myxoxanthin*, myxoxanthophyll*	Uncertain
4.	Bacillariophyceae	*Chlorophyll-a* Chlorophyll-c	α-carotene, *β-carotene*, e-carotene**,†	Lutein (?)**, *fucoxanthin*, neofucoxanthin A, B, diatoxanthin, diadinoxanthin,	Not reported
5.	Phaeophyceae	*Chlorophyll-a* Chlorophyll-c	α-carotene, *β-carotene*	Lutein, viola-xanthin, flavoxanthin, neoxanthin, *fucoxanthin*, neofucoxanthin A, B, diatoxanthin**, diadinoxanthin, zeaxanthin (?)†	Not reported
6.	Rhodophyceae	*Chlorophyll-a* Chlorophyll-d**,†	α-Carotene, *β-carotene*, e-carotene*	*Lutein***, zeaxanthin**, taraxanthin (?)**, violaxanthin†, flavacin*, flavoxanthin*, neoxanthin*, fucoxanthin*, neofucoxanthin A, B*, diadoxanthin*, dinoxanthin*, neodinoxanthin*, peridinin*, myxoxanthin*, myxoxanthophyll*	r-*phycoerythrin*, r-phycocyanin, β-phycoerythrin**, allophycocyanin**,‡
7.	Myxophyceae	*Chlorophyll-a*	*β-Carotene*, flavacene, e-carotene†, α-carotene*	Lutein, zeaxanthin, *myxoxanthin***, *myxoxanthophyll***, oscilloxanthin**, flavacin*, violaxanthin*, flavoxanthin*, neofucoxanthin A, B*, diatoxanthin, diadinoxanthin*, dinoxanthin*, neodinoxanthin*, peridinin*, aphanizophyll*, antheraxanthin*	c-phycoerythrin, c-*phycocyanin*, allophycocyanin**

Food Reserves

Since the early steps in photosynthesis in all the algal groups are practically the same it is but natural that the primary products of this process must also be the same. The food materials which accumulate as food reserves in the form of polysaccharides, however, vary from group to group and thus provide useful data for preliminary classification of algae. True starch is typical of only two algal divisions namely, Chlorophyta and Charophyta. The two other kinds of characteristic starches are the **cyanophycean starch** and **floridean starch**. The former is characteristic of division Cyanophyta and the latter of division Rhodophyta. The three other important polysaccharides which accumulate as reserve food are **laminarin** found in the brown algae, **paramylon** characteristic of Euglenoids and **leucosin** peculiar to the Xanthophyta, Bacillariophyta and Chrysophyta. Besides, a proteinaceous compound **cyanophycin** is found only in the cells of blue-green algae. Mannitol which was formerly considered to be unique to the brown algae has recently been reported to occur in a few red algae. Fats occur as reserve food in appreciable amounts in the cells of Xanthophyta, Bacillariophyta and Chrysophyta. The environmental factors which favour growth of the algae are favourable temperature, suitable light, and proper supply of oxygen, carbon dioxide and essential elements.

Algal Flagella

The motile cells of algae are provided with fine, protoplasmic, whiplike threads, the **flagella**(A). They are extremely fine and hyaline emergences of the cytoplasm. In cells possessing firm cell walls, the flagella are connected with the inner cytoplasm through small pores in the cell wall (C). There is either a single anterior flagellum (rarely posterior) or the flagella occur in pairs (A), rarely in great numbers on the cell. The flagella on the cell may be equal (**isokont**) or unequal (**heterokont**) in length. When the flagella are inserted laterally one is directed forwards in motion and the other backwards. They function as the locomotory or propelling structures of the cell. Usually there is a single granule at the base of each flagellum. It is known as the **blepharoplast**.

(*a*) *Structure of the Flagellum.* Forming the core of the flagellum is an axial or central filament called the **axoneme**. The latter is surrounded by a cytoplasmic membrane or sheath which terminates short of the apex (C). The naked, terminal portion of the axoneme is called the **end piece**. The tip of the end piece may be blunt and rounded or pointed. In cross-section (E) the flagellum consists of two inner central simple fibrils forming an elastic axial thread. It is surrounded by nine united, peripheral contractile, thicker protein double fibrils. All are enclosed by sheath which is an extension of the plasma membrane. Each peripheral fibril is composed of two thin fibrils. The two central fibrils are single. They lie side by side and are sometimes enclosed by a sheath of their own. The fibrils are hollow and extend along the entire length of the flagellum. The nine peripheral fibrils join the basal granule (C) but the two central fibrils stop short of the granule. This '9+2' pattern of component fibrils is the basic structure of the flagellum of all organisms except the bacteria.

(*b*) *Kinds of Flagella.* They are of two main types, **whiplash** (A) and **tinsel (B)**. The whiplash flagellum has a smooth surface. The tinsel flagellum bears longitudinal rows of fine, minute flimmer hairs arranged along the axis almost to the tip of the flagellum. There may be a single row of hairs as in the Euglenophyta and Pyrrophyta or two as in Chrysophyceae and Phaeophyceae. The hairs arise from the margins of the peripheral fibrils. The whiplash or smooth flagella are also known by other names such as *acronematic* or *peitchgeisel*. The other names for the tinsel flagella are *pantonematic, flimmer* or *flimmergeisel*. The use of an electron microscope has revealed a third kind of flagellum in which the surface of the flagellum is covered by scales (*Chara*) and minute, short, stiff hairs. Manton and Parke (1960) described this type of flagellum in *Micromonas pusilla* (Prasinophyceae). The hairs differ from those on the tinsel type. They can be easily detached.

(*c*) *Flagellation*. The position, number and kind of flagella on the motile cells is strikingly constant in each division of algae but differs from division to division. Thus it forms an important taxonomic feature for primary classification of algae. The blue-greens and red algae lack flagella. The motile cells in green algae and stoneworts usually have two, rarely four equal flagella of whiplash type inserted at the anterior end (A and B). The only exception is the Oedogoniales in which the motile cells have a crown of flagella (C). The yellow green algae (Xanthophyceae) have two unequal anterior flagella. One of these is of whiplash type and the other tinsel (D). The diatoms (Bacillariophyceae) are characterized by a single tinsel flagellum on the male cell at the anterior end(E). In brown algae only the reproductive cells are motile. They are furnished with two laterally inserted unequal flagella. One of these is of tinsel type and other whiplash (F).

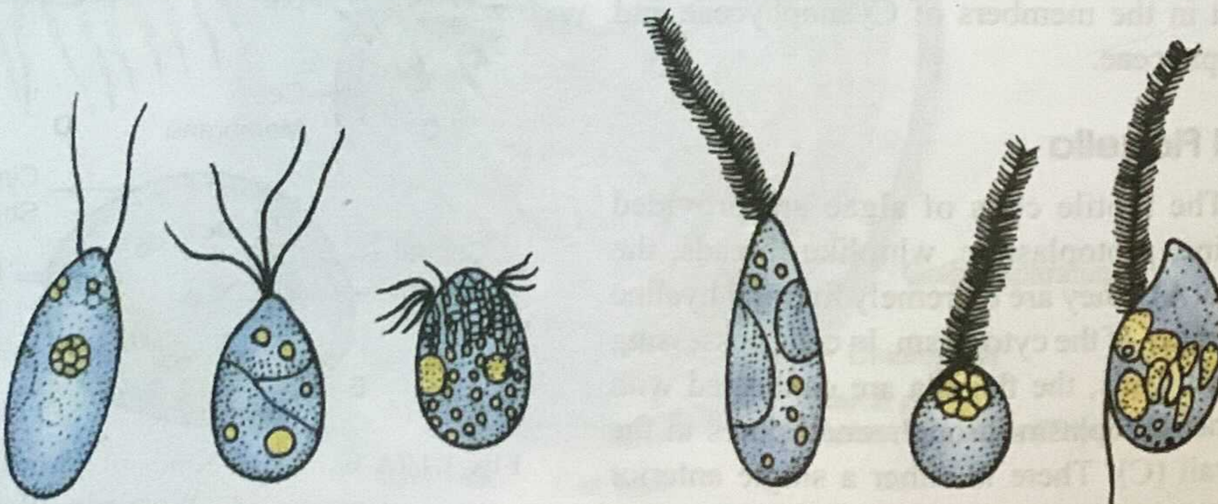

Fig. 1.5 (A-F). *Algae.* Flagellation., Chlorophyceae (A-C); Xanthophyceae (D); Bacillariophyceae (E) and Phaeophyceae (F).

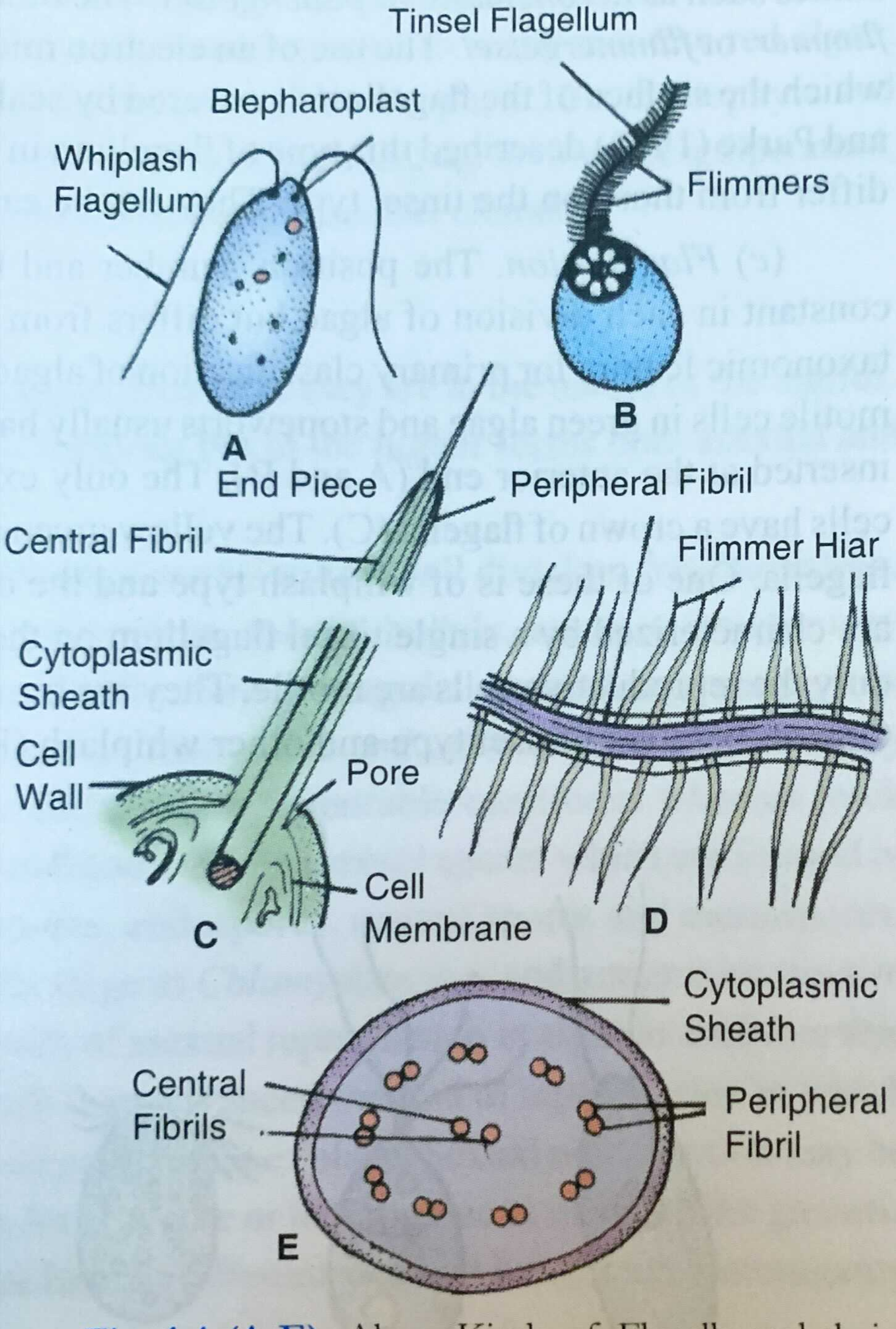

Fig. 1.4 (A-E). Algae. Kinds of Flagella and their structure. (A), Whiplash; (B). Tinsel; (C), L.S. Whiplash Flagellum; (D), L.S. Tinsel Flagellum; (E), C.S. Eukaryotic Flagellum.

15.1 WHAT IS A WATER BLOOM?

A "*bloom*" is a visible increase in the numbers of a species, usually an algal species, in the *plankton*. (*Plankton* is the large community of microorganisms that floats freely in the surface waters of oceans, seas, rivers and lakes). Since blooms are found in water, they are also called *water blooms*.

A bloom of diatoms (Bacillariophyceae) is often seen in the springs, which decreases later in the year, probably as available silica in their walls is used up. Sustained algal blooms may lead to *eutrophication*. (*Eutrophication* is a process which can occur in rivers, shallow lakes and other water bodies when the addition of extra nutrients, e.g. from fertilizers, causes heavy growth of algae. When the algae die, their decay by bacteria reduces the concentration of oxygen in the water, so that aerobic organisms may not survive).

Plant plankton are called *phytoplankton*. They include many microscopic algae, particularly diatoms and blue-greens. They form the base of the food chain in water, being eaten by animal plankton or zooplankton, which in turn provide food for fishes. It has been estimated that over 90% of the photosynthetic activity is carried out by phytoplanktons.

Abundant amount of particular alga/or algae, forming water bloom, provide a distinct colour to the entire body of water. The colour of water bloom, therefore, depends on the colour of alga/or algae forming bloom.

15.2 WHICH ALGAE FORM WATER BLOOMS?

Cyanophyceae or blue-green algae are mainly responsible for the formation of water blooms. However, blooms are also formed by some members of Chlorophyceae, Chrysophyceae, Bacillariophyceae, Euglenophyceae and Pyrrophyceae.

1. ***Cyanophyceae:*** Species of *Microcystis* and *Anabaena* are the two most frequently reported blue-greens forming cyanophyte blooms. Some of the bloom-forming species of these two genera are *Microcystis aeruginosa*, *M. flos-aquae*, *M. scripta*, *M. viridis*, *Anabaena flos-aquae*, *A. catenula*, *A. circinalis* and *A. microspora*. Some other bloom-forming blue-greens along with their common bloom-forming species in parenthesis include *Anabaenopsis* (*A. elenkinii*), *Coelosphaerium* (*C. dubium*, *C. kuetzingianum*), *Gloeotrichia* (*G. natans*), *Lyngbya* (*L. limnetica*), *Nostoc* (*N. carnium*, *N. linkia*), *Nodularia* (*N. spumigena*), *Oscillatoria* (*O. agardhii*, *O. planktonica*, *O. prolifica*), *Spirulina* (*S. gomontiana*) and *Trichodesmium* (*T. erythraeum*). *Aphanizomenon flos-aquae* is the least frequently bloom-forming cyanophyte (Carmichael, 1981).
2. ***Some other bloom-forming algae:*** Some other common bloom-forming algae belong to Bacillariophyceae (*Fragilaria*, *Tabellaria*), Chlorophyceae (*Cosmarium*, *Mougeotia*, *Oedogonium*, *Pandorina*, *Scenedesmus*, *Volvox*, *Zygnema*), Chrysophyceae (*Synura*), Cryptophyceae (*Hornellia*), Eugleninae (*Euglena*) and dinoflagellates (*Gymnodinium*). *Phaeocystis* is an example of Chrysophyta, in which the floating gelatinous colonies can form blooms so dense that the sea gets locally discoloured and migration patterns of fishes are adversely affected. Gallois (1976) has shown the evidence that *Gephyrocapsa huxleyi* blooms of coccolithophorids of Chrysophyta in the past might have been responsible for the origin of oil in the North Sea.

15.3 ALGAE FORMING WATER BLOOMS IN INDIA

1. ***Temple ponds, lakes and other permanent water-containing bodies:*** *Microcystis aeruginosa* and *M. flos-aquae* are the two most commonly found bloom-forming algae of these aquatic surroundings in India. Some other algae are several species belonging to *Spirulina*, *Anabaenopsis*, *Oscillatoria*

and *Raphidiopsis* of Cyanophyceae; *Chlorogonium, Eudorina, Closterium, Cosmarium* and *Volvox* of Chlorophyceae; *Navicula, Nitzschia, Melosira,* and *Cyclotella* of Bacillariophyceae; *Euglena* of Euglenineae; and *Synura* of Chrysophyceae.

2. **Salty lakes:** *Anabaenopsis, Oscillatoria* and *Spirulina* are common bloom-forming algae of salty lakes (e.g. Sambhar Lake of Rajasthan) of India.
3. **Esturine Areas:** *Anabaenopsis arnoldii* is a common bloom-forming cyanophyte of rivers of esturine areas in South India.
4. **Indian seas and Indian Ocean:** In Arabian Sea, Bay of Bengal and Indian Ocean, two common bloom-forming species of *Trichodesmium* are *T. erythraeum* and *T. theibautii.*

15.4 ALGAE FORMING WATER BLOOMS AROUND THE WORLD

Bloom-forming algae have been reported in the waters of almost all developing and developed countries of the world. Toxic blooms of marine species of *Lyngbya* have been reported by Graver and Arnold (1961) in Hawaii Island in Pacific Ocean and by Hoshimoto *et al.* (1976) in Okinawa (Japan). *Ptychodiscus brevis* form spectacular red tide blooms on the west coast of Florida, according to Steidinger (1983) while *Gonyaulax acatenella* form bloom in British Columbia (Prakash and Taylor, 1966). Annual blooms of *Prorocentrum minimum* occur in parts of Chesapeake Bay of USA. Three main bloom-forming algae of the world are *Microcystis aeruginosa, Anabaena flos-aquae* and *Aphanizomenon flos-aquae.*

A saline Magadi Lake of Kenya has a permanent bloom formed by a group of algae including *Anabaena, Chroococcus, Merismopedia, Oscillatoria* and *Synechocystis. Trichodesmium* forms a red colour bloom in the tropical parts of Atlantic Ocean, Red Sea and coasts of Australia. In the coastal parts of Australia, a very large area of about 52000 km^2 is occupied by blooms of *Trichodesmium.*

15.5 RED TIDES

"Red tides" are "blooms" produced by Dinoflagellates. In these blooms, the cells may be so great as to colour the ocean locally, red, reddish, yellow, or brown (Prakash and Taylor, 1966; Holmes *et al.* 1967; Sweeney, 1976). Dinoflagellate-blooms, forming very large patches may discolour the ocean upto several square kilometers. Majority of the dinoflagellate blooms, forming red tides usually occur in areas protected from strong winds. Surface waters of these blooms often contain very large number of cells (usually as many as 1 to 20 million cells per litre). Common red tide-producing dinoflagellates are *Ceratium, Cochlodinium, Gonyaulax, Gymnodinium* and *Prorocentrum.* Majority of these blooms are toxin-producers (Torpey and Ingle, 1966; Sasner *et al.* 1972; Steidinger and Joyce, 1973), resulting in fish kills and mortality of several other marine animals. Three categories of toxic blooms of dinoflagellates are given below:

1. Blooms that kill fish and few invertebrates, e.g. *Gymnodinium breve;*
2. Blooms that kill primarily invertebrates, e.g. species of *Gonyaulax;*
3. Blooms that kill few marine organisms and cause *paralytic shellfish poisoning* (PSP) in marine molluscs, e.g. *Gonyaulax catenella.* This dinoflagellate produces a poisonous toxin, called *saxitoxin*, which is a neurotoxin, one lakh-times more potent than cocaine (Steidinger and Joyce, 1973).

What Help in Setting off Dinoflagellate Blooms?

Dinoflagellate blooms seem to be set off by heavy rains on land. The run-off washes phosphates into the sea and also lowers the salinity, which promotes dinoflagellate growth. Vitamin B_{12}, required by majority of dinoflagellates, may also be washed into the sea from the soil during heavy rains on the land.

15.6 WHY ARE BLOOMS FORMED?

Algologists have put forward the ideas of several correlations between the formation of algal blooms and surrounding factors such as (i) light, (ii) temperature, (iii) inorganic nutrients, and (iv) water movements, but nothing has been conclusively proved in this direction. However, it is certain that mass production of any alga needs the presence of essential requirements of the optimum conditions in its surrounding water. Bloom formation needs the presence of major elements in the water. Several studies suggest the importance of the presence of vitamin B_{12} (cobalamine) in water for the formation of blooms of dinoflagellates. Most of the bloom-forming algae are blue-greens, and majority of them contain gas vacuoles, which help in floatation. Some believe that gas vacuoles also have definite correlation with the formation of blooms.

15.7 UTILITY OF BLOOMS

Several bloom-forming algae are common nitrogen-fixing agents, and thus help in increasing the fertility by fixing the nitrogen. Several such studies have been performed in different parts of the world including USA, England, Holland, Malaysia and Egypt. *Microcystis aeruginosa*, a very common bloom-forming alga, however, does not help in nitrogen-fixation. Some blue-green water blooms are also the major source of food for several birds and some aquatic animals. Flamingoes, the birds with pink feathers, specially feed on some blue-green algae, and it is suggested through some studies that pink colour of their feathers is mainly due to the carotenoids of these blue-greens.

15.8 DISADVANTAGES OF BLOOMS

Amongst several disadvantages of water blooms, a few are listed below:

1. Blooms are responsible for the death of fishes and several other aquatic animals, mainly because they deplete the amount of oxygen in the surrounding water.
2. They impart unpleasant taste to the water, making it unsuitable for drinking purposes.
3. Blooms sometimes emit foul smell, making the air unsuitable for perfect breathing.
4. Cyanophyte blooms have long been associated with animal poisoning. Common bloom-formers (e.g. *Microcystis aeruginosa*, *Anabaena flos-aquae* and *Aphanizomenon flos-aquae*) are confirmed toxin-producers (South and Whittick, 1987).
5. *Toxins* of *Anabaena* blooms have been termed as *anatoxins*. Alkaloids found in anatoxins are acutely toxic and produce neurological symptoms within minutes of ingestion. Peptides found in anatoxins produce liver necrosis.
6. Toxins of several cyanophyte blooms (e.g. *Schizothrix calciolata*) make the water unsuitable for drinking purpose and may even lead to gastroenteritis, according to Mynderse *et al.* (1977).
7. Toxins found in the blooms of dinoflagellates are responsible for neurotoxic shellfish poisoning in humans, fishes and sea birds.

15.9 HOW CAN BLOOMS BE CONTROLLED?

1. The best method of controlling blooms is to remove them by mechanical means as early as possible. But this method is not possible in large aquatic habitats like large ponds, lakes, rivers and seas or oceans.
2. Use of *algicides* (e.g. copper sulphate, chlorine, potassium permanganate, sodium chlorate, etc.) also prove quite helpful. These should, however, be used with utmost care and in low concentrations because they may prove detrimental for the growth and even very survival for many animals and other plants inhabiting the water along with the algal blooms.
3. Biological methods, like use of (i) specific viruses (e.g. cyanophages), (ii) bacteria, and (iii) fungi, parasitic on the blooms, are also used in several developing and developed countries.

(A) BENEFICIAL ASPECTS

22.2 ALGAE AS PRIMARY SOURCE OF FOOD AND ENERGY

The most important use of algae is that they are the "*primary producers* of organic matter in aquatic environment because of their photosynthetic activity" (Bold and Wynne, 1978). Animal life in aquatic environment mainly depends on algae because they form the primary source of energy and food for them. In aquatic ecosystems, the algae constitute the main part of the food chain. Because of their photosynthetic activity they continuously oxygenate (give out oxygen) their surrounding aquatic environment, which is beneficial directly to the other aquatic organisms.

22.3 ALGAE AS FOOD

More than 100 species, mostly of Phaeophyceae and Rhodophyceae, are used as food by man in different parts of the world. A few species of Chlorophyceae are also used as human food because of the presence of minerals, vitamins, carbohydrates and proteins, either in their cell wall or in their cytoplasm. Some of the important genera with their uses are mentioned below.

1. Among *Phaeophyceae*, some of the genera used as human food are *Alaria, Laminaria, Sargassum, Durvillea, Undaria, Eisenia, Ecklonia* and *Pelvetia*. In Japan, the food prepared from *Laminaria* is called *kombu*, and the food from *Alaria* is called *sarumen*. In South America, *Durvillea* is collected, dried, salted and sold as *Cachiyago*.

   The contents of food value of brown algae (Prescott,1969) include 6.15% protein (with 17 amino acids), 1.56% fat and 57.04% carbohydrates. Many minerals along with carotene, thiamin and subflavin are also found in brown algae.
2. Among *Rhodophyceae*, the important genera used as food are *Porphyra, Palmaria, Chondrus, Gigartina, Gracilaria, Gelidium, Eucheuma* and *Rhodymenia*.
   i. *Porphyra* is most important red alga used as human food. It is variously "called *nori* in Japan, *laver* in England and United States, *sloke* in Scotland, and *luche* in Southern Chile" (Bold and Wynne, 1978). *Porphyra* preparations are very rich in vitamins B and C. In Japan alone, 29.5 million kg of *Porphyra* per year is used as food.
   ii. *Palmaria* is also eaten under different trade names in different countries, such as '*dulse*' in Canada, '*sol*' in Iceland and '*dillisk*' in Ireland.
   iii. *Chondrus crispus* is commonly called '*Irish moss*' and used in ice-creams and various other foods.
   iv. *Gigartina stellata* is used for the production of mucilage, which contains galactose sulphuric acid.

v. *Rhodymenia palmata* is used as a common food '*dulse*' by fishermen.
vi. Glycerol, sorbitol and dulcitol are some of the carbohydrates found in red algae.
vii. Floridean starch, produced from Rhodophyceae, is a glucose.

3. Among *Chlorophyceae*, the important algae used as food are *Monostroma*, *Ulva*, *Codium*, *Chlorella*, *Caulerpa* and *Enteromorpha*.
   i. *Monostroma* is used as a common food "*aonori*" in Japan.
   ii. *Ulva* is dried, salted and sold as '*cachiyugo*' similar to *Durvillea*. It is also used as salad.
   iii. *Codium* is used as salad in Japan and many other countries.
   iv. *Chlorella* is well-known for its high percentage of lipids and proteins. "As much as 8.5% dry weight may be lipid content" (Prescott, 1969). The *Chlorella* protein has all essential amino acids, and therefore it is used as a *food in space-flights*. Although *Chlorella* can be a good substitute for food in crisis, its culture is very expensive. According to Thacker and Babcock (1957), production of *Chlorella* is not economic. As it has an antibiotic, *chlorellin*, its use as a food is also discouraged.
4. Among the blue-green algae, *Nostoc commune* is used as a food called '*yuyucho*' in China, Java, etc. *Spirulina* has a protein content in excess of 60% and is extensively cultivated (Shelef and Soeder, 1980).
5. Diatoms are also used as food in some parts of the world.

Seaweeds are an excellent source of *vitamins* including vitamin C at levels equivalent to citrus fruits and vitamins A, D, B_1, B_{12}, riboflavin, niacin, pantothenic acid and folic acid. According to Yamamoto *et al*. (1979), seaweeds also provide all the required trace elements for human nutrition.

22.4 AGAR

Agar is a jelly-like mucilaginous Carbohydrate, obtained from some genera of Rhodophyceae. It is universally used as a base for different culture media in laboratories for culturing many fungi, bacteria and some algae. Important agar-producing genera are *Gelidium, Gracilaria, Ahnfeldtia, Hypnea, Campylaephora, Pterocladia, Eucheuma, Gigartina, Chondrus* and *Phyllophora*.

The universal use of agar in culture media is mainly because it (i) contains galactose and a sulphate, (ii) melts between 90–100 °C, (iii) becomes solid at low temperatures, and (iv) is resistant to attack by almost all microorganisms.

Agar is also used in packing canned foods, in treatment of constipation, and in cosmetic, leather, textile and paper industries. It is also often given as a laxative.

Agarose, a neutral gelling component obtained from agar, is now used as a gel in chromatographic and electrophoretic studies (Pluzeck, 1981).

Dried agar is used for prolapsed stomach by the physicians. Many pills and ointments are also prepared by using agar.

Agars, carrageenins and alginates are three major types of commercial *phycocolloids* produced from algae.

22.5 CARRAGEENIN

Carrageenin is a phycocolloid obtained from the members of Hypneaceae, Phyllophoraceae, Solieriaceae and Gigartinaceae of Rhodophyceae. It is a complex of D-galactose-3, 6-anhydro-D-galactose and monoesterified sulphuric acid found in the cell wall of *Chondrus crispus* and many other red algae. It is used in the preparation of tooth-pastes, cosmetics, paints, and in leather finishing, textile, brewing and pharmaceutical industries. Physicians also use carrageenin as a blood coagulant. It is also used as a clearing agent in juices, liquors, beet sugar, etc. Carrageenin is also used in the food industry as an emulsifier, particularly in dairy products. *Gigartina, Eucheuma, Iridaea* and *Hypnea* are also used for the extraction of carrageenin.

22.6 ALGINATES

Alginate derivatives and alginic acid are extracted from the cell wall of some brown algae, such as *Laminaria, Macrocystis, Durvillea, Ascophyllum, Ecklonia, Lossonia, Fucus, Cystoseira, Eisenia*, etc.

Algin, with a formula of $(C_6H_8O_6)_n$, is a carbohydrate originating in the cell wall. Alginic acid occurs in the middle lamella and primary walls of some members of Phaeophyceae.

Alginates are used in rubber tyre-industry, paints, ice-creams and also in the preparation of flame-proof fabrics and plastic articles. For stopping the bleeding effectively, alginic acid is used. Alginic acid derivatives are also used in the preparation of soups, creams, sauces, etc.

Chapman and Chapman (1980) described the details of the commercial production of alginates.

22.9 AS FODDER OR ANIMAL FOOD

Algae constitute a source of "permanent food" for many animals, including foxes, deer, rabbits and bears. These include mainly the members of Phaeophyceae, Rhodophyceae and some green algae.

1. *Laminaria*, *Sargassurn*, *Fucus* and *Ascophyllum* are used as fodder in many areas of the UK and Japan. *Macrocystis* is used for cattle-feed because it is rich in vitamins A and E.
2. Hens, which feed on *Ascophyllum*-meal and *Fucus*-meal, produce eggs with increased iodine content.
3. Seaweed-meals also increase the butter-fat content of the milk in feeding cattle.
4. A fish, named *Tilapia*, uses only the members of Cyanophyceae and Chlorophyceae as its food.
5. Many fishes depend for their food only on diatoms.
6. Stock-feed and commercial feed are regularly processed for many cattles, specially sheep and horses, from species of *Laminaria*, *Ascophyllum* and *Fucus*.
7. The major food of many fishes, protozoans, crustaceans and many other aquatic animals is provided by planktonic algae.
8. *Rhodymenia* is a common cattle-food in France,
9. In Japan, *Pelvetia* is used as a cow-feed.

22.11 AS FERTILIZER*

Because of the presence of phosphorus, potassium and some trace elements, the seaweeds in many coastal regions of the world are used as *fertilizer*. They are either mixed with some other organic materials or are allowed to rot in the field as such.

1. Genera like *Lithophyllum*, *Lithothamnion* and *Chara* are used in the deficiency of calcium in the field.
2. *Fucus* is used as a common manure by Irish people.
3. A 30% increase in the total production of rice grains was reported by algologists at Central Rice Research Institute, Cuttack, when the rice fields were inoculated by some nitrogen-fixing blue-green algae.*
4. Several brands of liquid fertilizers prepared from seaweed are now available in the market. They are used in intensive gardening and greenhouse horticulture (Stephenosen, 1981).

Chapman and Chapman (1980) have reviewed the use of seaweeds as fertilizers and other medicines.

22.12 ANTIBIOTICS AND OTHER MEDICINES

An antibiotic, *chlorellin*, is obtained from *Chlorella*. Some antibacterial substances, effective against Gram-positive and Gram-negative bacteria, were also reported from *Ascophyllum nodosum, Rhodomela larix, Laminaria digitata* and some species of *Pelvetia* and *Polysiphonia*. An antibiotic, effective against some bacteria, has been prepared from a diatom *Nitzschia palea*. It is specially effective against *Escherichia coli*.

People of maritime nations extensively use seaweeds as their traditional medicines as vermifuges, ointments and anaesthetics, as well as for the treatment of cough, gout, goitre, hypertension, veneral diseases and even for cancer (Stein and Borden, 1984). Iodine contents of *Laminaria* check goitre.

"*Tse-ko-Tsoi*", an antihelmitic drug, is prepared from a red alga *Digenia simplex* in China.

Fucoidin and sodium laminarin sulphate, obtained from some brown algae, are used as anticoagulant of blood. Some algae are also used in the treatment of the diseases of kidney, urinary bladder and lungs.

Antiviral compounds, reported to be present in some red algae, are used in treating herpes viruses (Ehresmann *et al* 1979). Extracts of *Laminaria* and *Sargassum* inhibit the growth of sarcoma and leukaemia cells in mice, according to Yamamoto *et al*. (1982).

The saxitoxins produced by some dinoflagellates are used in some neurological disorders and neurobiological researches (Schantz, 1981).

In an article entitled "Vital Drugs from Algae", Dr. G.S. Venkataraman, a great Indian algologist, stated that blue-green algae "can be a source of vital pharmaceutical compounds, and may play a role in biological warfare against mosquitoes"... "Scientists have recently succeded in isolating two important medicinal compounds from blue-green algae"..... "One was the chemical cytonemin derived from *Scytonema*, and was found to be effective against *skin cancer*. The second was obtained from *Tolypothrix*, and is generally administered during *heart attacks* to improve blood circulation."

22.13 IN BIOLOGICAL RESEARCH

The cultures of *Chlorella, Scenedesmus, Anacystis*, etc. are widely used in many physiological researches, specially in the investigation of photosynthesis.

22.14 IN SEWAGE DISPOSAL*

Sewage consists mainly of domestic and industrial wastes. The disposal of this sewage is mainly an aerobic process, and this oxygenation is facilitated mainly by some algae, e.g. *Chlamydomonas, Chlorella, Euglena, Scenedesmus*, etc. The aeration of sewage is essential, specially in smaller sewage bodies or ponds, to avoid unpleasant odour.

22.15 ALGAE AND LAND RECLAMATION

Land reclamation is effected mainly by algae. After rains, the members of Chlorophyceae and Cyanophyceae develop and check soil erosion on disturbed or burned soils. On the alkaline *usar* land of north India, extensive growth of blue-green algae was reported by Singh (1961). This increased the nitrogenous content and ultimately made the soil satisfactorily fertile.

16.5 ALGAE AS INDICATORS OF WATER POLLUTION

About a century ago, Kolkwitz and Marsson (1908, 1909) studied the pollution oriented changes in the composition of algal communities of a river and identified three major zones of the polluted river, viz. polysaprobic zone, meso-saprobic zone and oligosaprobic zone.

1. The zone, containing high molecular decomposable organic matter, having deficiency of oxygen, and characterized by algae like *Euglena* and *Oscillatoria*, is called *polysaprobic zone*.
2. The zone, deficient in too-much decomposed organic matter, having an easy availability of oxygen, and characterised by algae like *Phormidium*, *Ulothrix* and *Oscillatoria*, is called *mesosaprobic zone*.
3. The zone, containing little or no decomposition of organic matter, having plenty of oxygen-availability, and characterised by algae like *Calothrix*, *Meridion*, *Batrachospermum* and *Cladophora*, is called *oligo-saprobic zone*.

On the basis of additional data of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) scientists have now modified the above-mentioined three saprobien zones of Kolkwitz and Marsson into as many as nine or more zones (Patrick, 1977).

16.5.1 Algae as Indicators of Organically Polluted Waters

Extremely polluted water contains only bacteria. It generally contains no algae because of the existence of anaerobic conditions. Organically polluted water, having sufficient amount of oxygen, contains several algae belonging to Cyanophyceae, Chlorophyceae, Bacillariophyceae and Euglenineae. Some of the commonly reported species indicating the presence of organically polluted water are listed below:

1. **Blue-green Algae:** *Anabaena constricta, Aphanocapsa montana, Lyngbya digueti, Oscillatoria chlorcina, O. limosa, O. princeps, O. tenuis* and *Phormidium autumnale.*
2. **Green Algae:** *Carteria multifilis, Chlamydomonas reinhardtii, Chlorella vulgaris, Chlorococcum humicolum, Pandorina morum, Scenedesmus quadricauda, Spirogyra communis* and *Stigeoclonium tenue.*
3. **Diatoms:** *Achnanthes exigua, Cyclotella meneghiniana, Melosira varians, Navicula cryptocephala, Nitzschia palea* and *Synedra ulna.*
4. **Euglenoids:** *Euglena viridis* and *Phacus longicauda.*

16.5.2 Algae as Indicators of Home Sewage

The home sewage of open water channels alongside of roads contains several species of *Oscillatoria* (*O. amphibia, O. boryana, O. rubescens*), *Nostoc* (*N. commune, N. microscopicum*), *Anabaena* (*A. flos-aquae, A. cylindrica*), *Euglena* (*E. acus, E. gracilis, E. granulata*), *Spirulina major*, *Schizomeris leibleinii* and *Stigeoclonium variabile.*

16.5.3 Algae as Indicators of Industrial Wastes

Presence of some algal species in the industrial wastes indicate the presence of some specified elements and chemicals or salts in the waste. Some of such examples are listed below:

1. **Chromium:** *Closterium acerosum, Euglena viridis, Nitzschia palea, Navicula cuspidata.*
2. **Copper:** *Calothrix braunii, Scenedesmus obliquus, Navicula viridula.*
3. **Distillary Wastes:** *Chlorobrachis gracillima, Chlorogonium gracillima.*
4. **Highly-acidic Industrial Waste:** *Chromulina ovalis, Euglena viridis, E. stellata, Cryptomonas erosa.*
5. **Hydrogen Sulphide Wastes:** *Achnanthes affinis, Cymbella ventricosa, Navicula minima, Nitzschia palea.*
6. **Iron:** *Pinnularia subcapitata, Surirella linearis.*
7. **NaCl-containing Waste:** *Chlamydomonas ehrenberghii, Enteromorpha prolifera, Spirulina subsalsa, Melosira arenaria, Navicula subtilissima, Nitzschia apiculata.*
8. **Oil Waste:** *Amphora ovalis, Diatoma vulgare, Melosira varians, Navicula radiata, Synedra acus.*
9. **Paper-mill Waste:** *Pandorina morum* , *Ulothrix zonata, Oscillatoria splendiata, Cymbella ventricosa, Amphora ovalis, Diatoma vulgare, Surirella ovata.*
10. **Phenolic Waste:** *Cocconeis placentula, Diatoma vulgare, Gomphonema parvulum, Pinnularia borealis, Synedra ulna.*

16.5.4 Diatoms as Indicators of Pollution

Studies have suggested that population of members of Bacillariophyceae can be used as indicators for estimating the type and quality of water i.e. whether the water is polluted, treated or raw. *Catherwood Diatometer*, developed by Patrick (1977), is used for the purpose.

Polysaprobic zone, where oxygen is completely depleted, usually lacks diatoms. *Nitzschia palea* and *Gomphonema parvulum* usually occur in mesosaprobic zone where water is, of course, polluted but oxygen is not completely depleted. Decreasing number of species of diatoms indicates the presence of decreasing pollution of water. Patrick (1956) opined that diatoms are more widely used as indicators of pollution than other algal groups because they require no special preservatives due to the presence of silica in their wall. With the help of Catherwood Diatometer, Patrick (1977) concluded that "with increased pollution, the species of diatoms decrease while at the same time the individuals of each species of diatoms increase", thus showing the inversely related nature of the species and individuals of diatoms.

14.10 ECOLOGY OF ALGAE IN SYMBIOTIC ASSOCIATIONS

Some algae grow symbiotically in close association with other organisms such as fungi, bryophytes, vascular plants, and invertebrates including Protozoa. A few occur also as parasites. They all show mutualistic and commensalistic associations along with some degrees of parasitism.

14.10.1 Algae-Fungal Associations

Several algal live in close *symbiotic associations* with some fungi in the form of *lichens*. This is such a symbiotic relationship that the resultant "lichen" has definite morphology, physiology, and ecology, quite different from that of their algal or fungal component. Major partner in a lichen is, however, the fungus (mycobiont), which sometimes form as much as 90% of the lichen biomass. Two major algae found in many lichens are *Trebouxia* and *Pseudotrebouxia*.

Researches indicate a one-way flow of nutrients from the alga to the fungus, made up of carbohydrates in the primary thallus and ammonia in the cephalodia. Out of the total carbon fixed in the photosynthesis by the alga, up to 90% moves to the fungus. Ahmadjian (1981), the great lichenologist, opined that the ability of lichens to fix atmospheric nitrogen is dependent mainly upon their possession of blue-green algae, either as the main phycobiont or as the part of cephalodium. Nitrogen fixation occurs in the heterocysts of the blue-green algal phycobiont. Some marine algae and marine fungi also live in symbiotic associations, but these are not regarded as true lichens. Kohlmeyer and Kohlmeyer (1972) have termed them as *mycophycobioses*. For more details of algae-fungal associations, readers may refer to Ahmadjian (1981), Lawrey (1984) and Kershaw (1985).

14.10.2 Algae-Bryophyte Associations

Algae, mainly members of Cyanophyceae possessing heterocysts (e.g. *Nostoc*, *Anabaena*) are found in association with several bryophytes (e.g. *Anthoceros*, *Blasia*). According to Stewart and Rodgers (1977), the bryophyte member supplies fixed carbon to the alga while alga excretes nitrogen as ammonia which is taken up by the bryophyte. In this symbiotic association, the activity of glutamine synthetase is checked. On isolation of the alga, this activity, however, resumes.

14.10.3 Associations of Algae and Vascular Plants

Interesting algal associations are seen with some pteridophytes (e.g. *Azolla*; Fig. 14.4), gymnosperms (e.g. *Cycas*; Fig. 14.5) and angiosperms (e.g. *Gunnera*). Peters and Calvert (1983) have investigated these associations in detail.

Anabaena azollae filaments are present in cavities in the dorsal lobes of the floating leaves of *Azolla filiculoides* (Fig. 14.4). It is very difficult to isolate these algal filaments from the leaves of *Azolla*. According to Peters and Calvert (1983), these filaments are incapable of a free-living existence. In the algal filaments, even the initial divisions and formation of heterocysts take place within the cavity of the leaf of *Azolla*. The algal filaments fulfill all the nitrogen requirements of their host (i.e. *Azolla*).

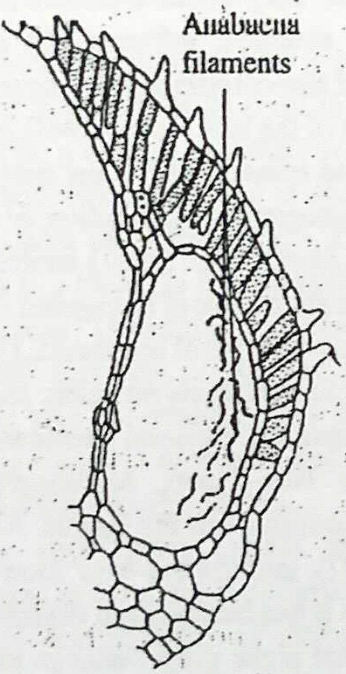

Fig. 14.4 L.S. dorsal lobe of the leaf of *Azolla filiculoides* containing filaments of *Anabaena azollae* inside the lobe.

Some higher vascular plants show associations with cyanophytes. Coralloid roots of *Cycas* contain a definite algal zone (Fig. 14.5) from which Fritsch (1935) reported several organisms including *Anabaena cycadae*, *Nostoc punctiforme*, *Oscillatoria*, some bacteria (e.g. *Azotobacter*, *Pseudomonas*) and even a few fungi. Amongst the angiosperms, *Gunnera* shows association with some algae (e.g. *Nostoc*). Filaments of *Nostoc* become exceptionally intercellular in *Gunnera*.

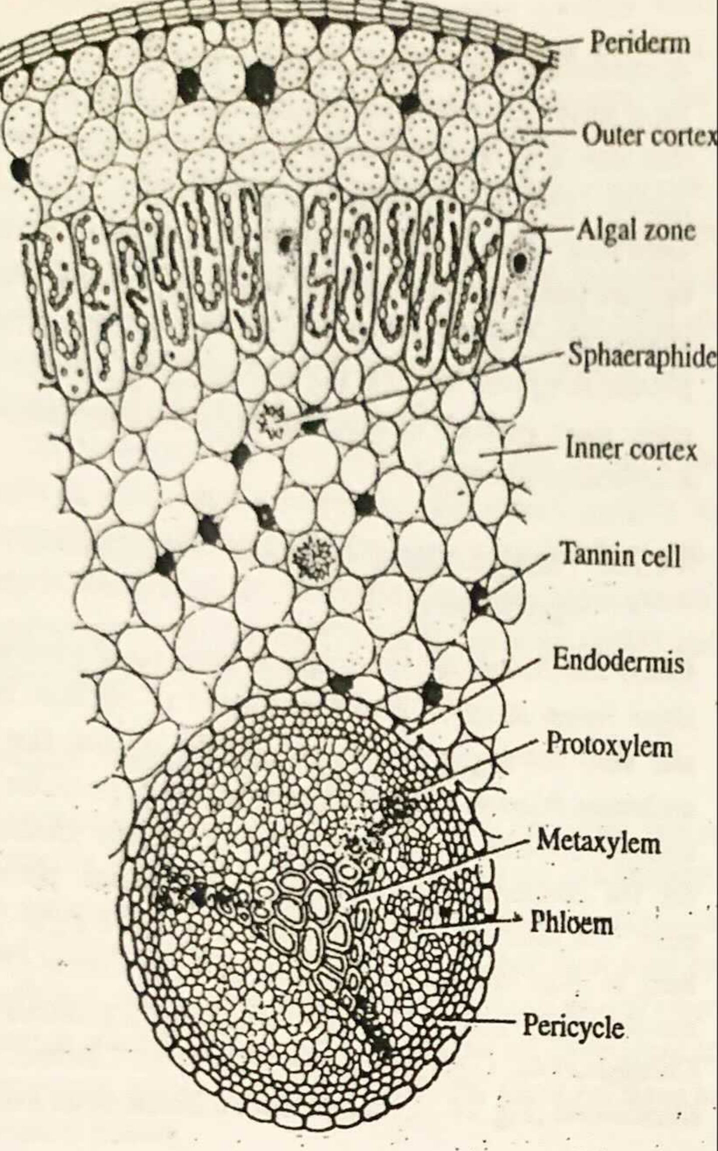

Fig. 14.5 T.S. coralloid root of *Cycas revoluta* showing a clear algal zone containing filaments of *Anabaena cycadae*.

14.10.4 Ecology of Algae-Protozoa Interactions

Foraminiferans, members of Sarcodina of Protozoa, are hosts of several algae belonging of Chlorophyceae, Dinophyceae, Bacillariophyceae and Rhodophyceae. These protozoans occur abundantly in shallow tropical and subtropical seas. According to Lee (1980), Foraminiferal sands provide a tight recycling of phosphorus and nitrogen between the alga and its host. Light is an essential requirement for the growth of some species. According to Rottger *et al.* (1980) *Amphistegina lessonnii* grows at a rate proportional to light intensity. It does not show any growth in dark even when provided with sufficient food. In all these associations, the animal receives carbon from the alga, but its actual mechanism is not clearly known. Some studies suggest that the carbon fixed by the alga may pass to the host after the death of the alga (Lee and McEnery, 1983).

14.10.5 Ecology of Algae-Invertebrate Associations

This aspect has been worked out by several algologists as well as Zoologists including Taylor (1973), Trench (1982), Glider and Pardy (1982) and Goff (1983). A definite chloroplast and cyanelle-based association occurs in sarcoglossan molluscs, which feed on some siphonous green algae like *Caulerpa* and *Codium* (Trench, 1982). The photosynthate released by the *Codium fragile* plastids is metabolized in the hepatopancreas of the host. According to Hinde (1983), the mollusc feeds on the alga and the only benefit to the alga perhaps is from a reduction in grazing pressure. This, however, does not show the existence of a clear mutualistic association.

Several members of Cyanophyceae, Chlorophyceae, Bacillariophyceae, Dinophyceae and Rhodophyceae have been reported as endosymbionts from many freshwater and marine hosts. Glider and Pardy (1982) regarded the algae-invertebrate associations as stable composite organisms. According to Muscatine and Porter (1977), over 85% of the organic carbon of the host (coral) is obtained from the algae.

The exchange of metabolites between the host and the algae has been studied in many such associations. Majority of the studies have focused on the transfer of carbon from the alga to the animal. In corals, as much as 50% of the carbon is fixed. This carbon is found in the animal cell mainly as protein or lipid. It is, however, transferred mainly as glycerol. According to Ziesenisz *et al.* (1981), the translocated metabilite is maltose in *Chlorella*-based associations. Some studies show that corals with symbionts show active uptake of phosphorus and nitrogen.

14.5 PHYTOPLANKTON

Phytoplankton are the photosynthetic members of *plankton* (organisms floating in seas, rivers, ponds and lakes). These are the most widespread and most extensively studied of all ecological groups of algae. They occur in virtually all bodies of water, where they float freely. Almost all algal groups except Charales, brown algae and red algae contribute species to the phytoplankton flora. For detailed study of the ecology of phytoplankton, readers may refer Morris (1980), Round (1981) and Reynolds (1984).

Majority of the algal phytoplankton are unicellular. However, several members are colonial, cocci and filamentous fresh water forms, ranging from less than 5μm (cocci) to 500 μm (*Volvox*). Size of phytoplankton has important implications for buoyancy and nutrient absorption. Most common algal phytoplankton are diatoms, dinoflagellates, small blue-greens, Chlorophyceae, Chrysophyceae and small flagellates, principally prymnesiophytes. In nutrient-poor waters, Chrysophysceae and desmids predominate while in nutrient-rich waters, diatoms and Cyanophytes are usually found. According to Round (1981), small nutrient-enriched pools may be specially dominated by euglenophytes.

Diatoms constitute the most dominant algae in both freshwater and marine habitats, whereas desmids and chlorococcalean green algae are equally important in many freshwater habitats.

14.5.1 Flotation and Buoyancy

Phytoplankton population can survive only in such water bodies where irradiations will support photosynthetic levels sufficient for their net growth and reproduction. Movement in water bodies increases nutrient uptake, and it also helps in avoiding predators and high and damaging levels of irradiations.

Except that of gas vesicle-forming blue-greens, all algae have densities higher than water, and therefore must inevitably sink in the water. Motile algal species can actively swim towards light but diatoms and coccoid and filamentous forms cannot actively swim towards light. Densities of most of the cytoplasmic components of algal cells are higher than that of water. Diatoms form the most successful group of phytoplankton because their silica walls have a density of 2.6. Only lipids are less dense (0.86) than water.

Cyanophyceaen planktonic species possess flotation devices, such as gas vacuoles. They are made up of a number of closely packed cylinders or vesicles of about 1μm length and 70 nm diameter and surrounded by a proteinaceous membrane. *Anabaena flos-aquae*, when grown under low irradiance, produces gas vacuoles and becomes buoyant. If transferred to high irradiances, the vacuolation in this species decreases and buoyancy is lost. According to Margalef (1978), gas vacuolate species of blue-greens are not common in sea where the usual planktonic adaptations are to a turbulent environment. This environment reduces the effectiveness of flotation devices.

Water currents maintain most of the phytoplankton cells in the water bodies. The sinking rate of a phytoplankton cell is directly dependent on its size. A large-size cell will sink faster than a small-sized cell. The physiological status of diatoms also affect their sinking rate. The dead cells in an alga sink up to twice as fast as viable cells.

For more details on flotation and buoyancy, readers may refer Smayda (1970), Reynolds and Walsby (1975), Kahn and Swift (1978), Allison and Walsby (1981) and Reynolds (1984).

14.5.2 Light

Phytoplanktonic algae show tendency to modify their photosynthetic response to surrounding irradiances. Therefore, the algae, which are in the lower part of the photic region in water, will increase the concentration of their photosynthetic pigments and will thus reduce the level of light at which photosynthesis becomes saturated. Studies of Perry *et al.* (1981) indicate that this increase in concentration of chlorophyll is linked with an increase in the number of thylakoids per cell in the alga, and also that the size of photosynthetic unit enhances with reducing irradiance. Studies of Vesk and Jeffrey (1977) suggest that it is not only because of the decrease in total irradiance, but changes in chlorophyll concentration is also brought about by increase in the proportion of blue light which occurs with the increasing depth of water.

Algal ecologists are working to find out whether a permanent-shade phytoplanktonic flora occurs in the deeper waters of the oceans. Some algal species occur exclusively at depths of 100 m or more. Sournia (1982) reported 20 species of 12 genera of 5 classes of such algae preferring to occur in very deep waters. Inspite of occurring in such deep waters having low-light conditions, these algae do not show any common morphological adaptation. Geider *et al.* (1986) have shown some physiological adaptation to low-light levels in some such algae.

Sunlight also contains wavelengths about 700 nm (the infrared region), which are absorbed by water and show heating effect. Regular heating of surface water by such wavelengths of sunlight decreases the water density and shows definite impact on the phytoplanktonic algae. Density of coastal waters is also affected by reduction of salinity brought about by freshwater run-off from the land, or also from the melting of the ice of the sea. All these show definite affect on the algal flora occurring there in such waters.

14.5.3 Nutrients

Large number of both inorganic and organic nutrients are required by planktonic algae, and their availability to them has profound ecological importance. It is so because almost all algae, except diatoms, have the requirements of almost same macronutrients. Diatoms require silicates.

Effects of phosphates and nitrogenous compounds on phytoplankton populations have received greatest attention of the algal ecologists. The requirements of silicates for diatoms have also been studied in detail. Nitrogen is a macronutrient which often limits the growth of planktonic algae in marine environment. In freshwaters, the same role is performed by phosphorus according to Schindler (1977).

Sournia (1981) has proved that in a phytoplankton cell, the surface allows the exchange of energy and nutrients. For any type of the shape of the cell, it is the surface to volume (S/V) ratio which will decrease with increasing volume of the phytoplankton cell. Therefore, phytoplankton growth rate and S/V ratios are positively correlated. Harrison *et al.* (1977) have shown that S/V ratio increases in nutrient-deficient media. They also suggested that small-sized planktonic algae with high S/V ratios would grow luxuriently in *oligotrophic* (nutrient-poor) waters. Watson and Kalff (1981) have supported such observations also in fresh waters.

Addition of nutrients generally increases the growth rates as well as final biomass of any phytoplankton population. Studies suggest that nutrients are not always limiting for the growth of planktonic algae, even when they are at low concentrations and algal biomass is also low. Yentsch *et al.* (1977) have shown that when phytoplankton are grown under conditions of nitrogen deficiency, they show rapid uptake of bicarbonate ions in the dark if provided with a definite supply of ammonium ions.

Droop (1974) suggested that several phytoplankton are able to take up organic compounds in the dark. Similarly, Palmisano *et al.* (1985) observed that algae reported from the undersurface of the ice of Antarctic sea assimilate amino acids at surrounding concentrations, but these provide less than 1% of carbon obtained by photosynthetic fixation. According to Vincent and Goldman (1980), light stimulated the uptake of acetate by phytoplankton in the lower regions of the photic zone of Lake Tahoe of California (USA), but in algae present in the higher regions of water column, it shows no effect on uptake of acetate.

Nutrients constitute one of the major variables controlling phytoplankton community structure and biomass. Studies of Dillon and Rigler (1974) on the relationship between phosphorus concentration and chlorophyll suggest that phosphorus, nitrogen and silicon often become limiting resources. Addition of phosphorus in lakes increases algal biomass. The composition of algal species, however, changes by the addition of nutrients such as nitrogen and phosphorus. In many lakes, phosphorus is the key biomass-limiting nutrient. Productivity of some eukaryotic phytoplankton is maximized only when organic carbon is low.

Besides N and P, silicon, light and sometimes iron can have selective effects on phytoplankton species, as investigated by Huntsman and Sunda (1980). Some workers have shown strong correlation between the species composition of algal communities and inorganic carbon system (e.g. pH, alkalinity and dissolved organic and inorganic C). In fact, pH is the major factor in the chemistry of aquatic ecosystems and it influences strongly the kinetics of nutrient-uptake and also controls the chemical ions used by algae (Tilman *et al.* 1982).

14.5.4 Grazing

From the quantity point of view, the losses of phytoplankton due to predation are of great importance (Frost, 1980; Crumpton and Wetzel, 1982). Unicellular algae may suffer permanent loss due to parasitism or attack of microorganisms (Shilo, 1971). Zooplanktons are the major predators of planktonic algal flora. Major grazers of the marine planktonic algal flora include members of Protozoa, salps, pteropods and appendicularians. Crustaceans and rotifers are the major freshwater grazers.

Some diatom populations are grazed by fungal members, specially of Chytridiomycetes (Canter and Jaworski, 1978). Majority of the smaller species are specially susceptible to grazing. It has been reported by Porter (1973) that zooplankton grazing decreased the small cells in a population, and this ultimately resulted in an increase of larger algae such as desmids and dinoflagellates. Amongst algae, cyanophytes are least liked by grazers (Porter, 1973). Ecologists have established this fact that there is a negative correlation between phytoplankton and zooplankton density. The entire organic material of phytoplankton ingested by grazers is not assimilated by them. Several grazers release more than 30% of the organic carbon of phytoplankton in their faeces according to Eppley and Peterson (1979).

Porter (1976) opined that there exists an intimate link between grazing, nutrient recycling by grazers and growth of phytoplankton. Nival and Nival (1976) believe that the mortality co-efficient due to grazing mainly depends on the size of species of phytoplankton and size of the grazer.

14.5.5 Population Dynamics

No water body shows a uniform distribution of phytoplankton. Except that of some rare exceptions, each water body shows a considerable horizontal patchiness of phytoplankton. Vertical distribution of phytoplankton is also different in different water bodies. Both horizontal and vertical distribution of phytoplankton may also change time to time. Thus it is clear that boundries and species composition of phytoplankton change time to time.

In a freshwater pond, Happey–Wood (1976) studied vertical migrations of several flagellated algae (e.g. *Chroomonas*, *Cryptomonas*, *Mallomonas* and *Ochromonas*) for about 24 hours using a non-motile green alga (*Oocystis*) as a control. They noted that these algae moved down in the water column in the dark and returned back to the surface of the pond water during the day time. They were present in the subsurface waters under clear skies but under cloudy conditions, they were found on the surface.

Thoroughly studied aspects of phytoplankton ecology are seasonal changes. Several temperate lakes have been studied considering these changes. During winters, both temperature and light are low. Inspite of the abundant presence of the nutrients in the lakes during these seasonal changes, the standing crop of phytoplankton and its productivity are also low. When irradiance increases, as in spring seasons, there occurs a spurge in growth of the plankton. This ultimately leads to the formation of *bloom*. Formation of bloom continues until predation. The composition of various species of algae in the lake at any time depends on several factors, of which the most important one is the basal nutrient status of the waters. Diatoms dominate the blooms formed during springs. They are replaced by larger dinoflagellates and green flagellates during summers. In nutrient-rich waters, blooms of blue-greens usually develop in the warmer periods of the late summer. During autumn, as the surface water becomes cool, a second bloom of diatoms may again develop in the lake.

It has been observed that lakes of the high latitude regions differ from that of temperate regions in their prolonged period of ice cover. Even the permanently frozen lakes of polar regions support an algal flora. According to Round (1981), the species composition of such frozen lakes is highly variable. Ilmavirta and Kotimaa (1974), while working on the seasonal changes in biomass in high-latitude lakes, opined that there appears a correlation between species succession and the length of ice-free period in these lakes (Fig. 14.1). Tropical lakes, if compared with temperate lakes, show less seasonal variation. Most of them are nutrient rich (eutrophic) because of rapid remineralization occurring at higher water temperatures. Tropical lakes support a higher biomass of algae than temperate lakes. They also exhibit lesser species diversity than temperate lakes.

In the phytoplankton of the marine environment, diatoms dominate in the colder, eutrophic (nutrient-rich) waters, and coccolithophorids in the warmer *oligotrophic* (nutrient-poor) waters. Dinoflagellates occupy a somewhat intermediate position in the marine environment. Phytoplankton flora of coastal and oceanic waters, however, shows major ecological distinctions. Coastal regions show great variability in the species composition of their phytoplankton flora, mainly because they are undoubtedly influenced by run-off from the land and other human activities. The open oceans show definite latitudinal differences in species composition and seasonal changes. According to Round (1981), the phytoplankton flora of tropical oceanic waters is dominated by diatoms and coccolithophorids. For more details of phytoplankton distribution and species succession in marine environment, readers may refer Smayda (1980).

14.5.6 Species Succession and the Responsible Factors

Succession is defined as a change in species composition within a given water mass resulting from changing physical, chemical and biotic factors. Seasonal fluctuations in phytoplankton succession have been studied by several workers (Smayda, 1980; Tilman *et al.*, 1982). General successional sequence in lakes is controlled by two major types of factors. These are *allogenic factors* (e.g. water chemistry, temperature, turbulence, etc.) and *autogenic factors* (e.g. species competition, predation, parasitism and some other similar biotic factors). Species succession has a major role in phytoplankton dynamics. According to Smayda (1980), species succession is characterized by (i) co-occurrence of several species for varying durations and at different times, (ii) exhibition generally by each species of a population maximum, with the maximum abundance varying among the different species, and (iii) demonstration of concurrent peaks by several species.