1

Biology and Ecology of Microalgae

1.1. Biological characteristics

1.1.1. *General characteristics*

Microalgae are mainly photo-synthetic single-celled organisms living in aquatic environments (marine, brackish, fresh water) or humid or aerial terrestrial environments (atmosphere, soils, trees, building facades, etc.) (Sharma *et al*. 2006). They can also associate together to form colonies or undifferentiated multicellular organisms. The morphology and size of microalgae vary greatly according to species and taxonomic groups.

Microalgae are eukaryotic organisms that possess the main characteristics of the vegetable eukaryotic cell. They can be flagellated as in the case of algae belonging to the genus *Chlamydomonas* (see Figure 1.1) or not (see Figure 1.2). As eukaryotes, microalgae can be distinguished from cyanobacteria, which are prokaryotic organisms with a long life span and are called "blue-green algae" or Cyanophyceae. Spirulina (*Arthrospira* sp.), a well-known representative of this group, is, therefore, a photosynthetic bacterium and not an alga, as is often stated in commercial communication (Fleurence 2018).

Microalgae are also characterized by a great morphological diversity. This is the case of diatoms, which are distinguished from other algae by the presence of a siliceous shell called a frustule and whose architecture differs according to the species considered (see Figure 1.3) (Loir 2004). This unique morphological feature is the biological signature of diatoms, which are also known as "siliceous algae". This morphological heterogeneity is also found in size since microalgae generally vary in size from less than 1 μm to 1 mm.

The smallest size, 0.8 µm, is observed for the marine species *Ostreococcus tauri* (Borowitzka 2018a).

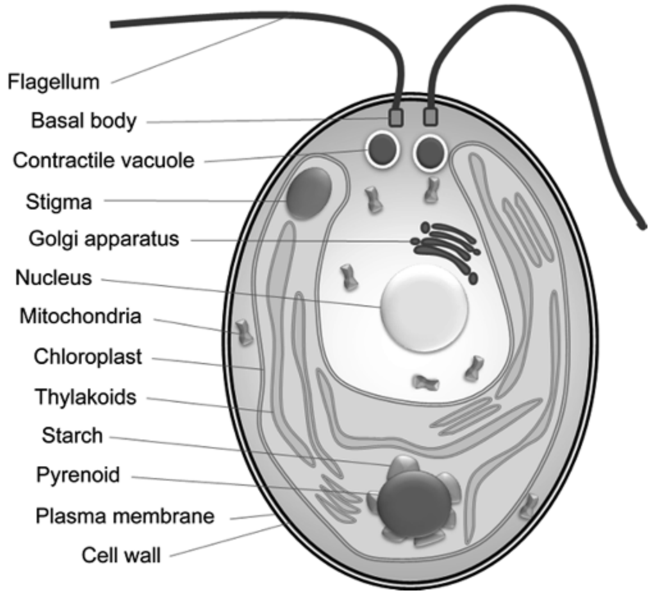


Figure 1.1. *Cellular organization of the microalga* Chlamydomonas *sp. (source: Pouchus Y.-F.). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

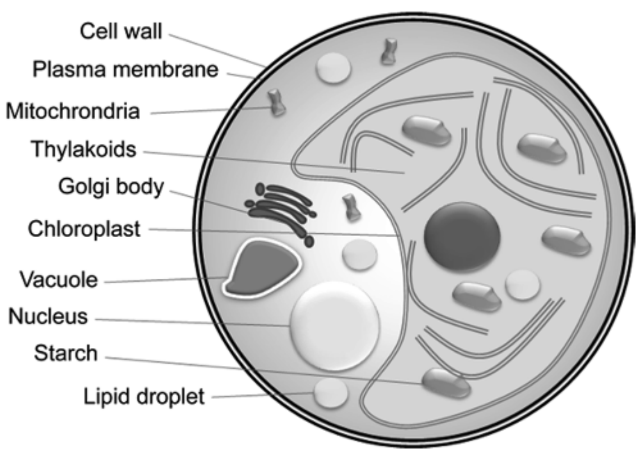


Figure 1.2. *Cellular organization of the microalga* Chlorella *sp. (source: Pouchus Y.-F.). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

1.1.2. *The different groups in traditional and phylogenetic classification*

Like all organisms, microalgae are classified into several taxonomic groups according to traditional or phylogenetic systematics. The traditional systematics establishes botanical phyla based on the pigment position of the microalgae. The pigment criterion, according to its nature, is an agglomerating or discriminating character. Thus, all algae, micro- or macroalgae, have a common pigment: chlorophyll a. This pigment is also present in cyanobacteria and terrestrial plants. The presence of additional pigments, called supernumerary pigments, is used as a distinguishing criterion to define the main algal phyla (see Table 1.1). These phyla, of which there are three, are, respectively, the phylum of Chlorophyta (green algae), Chromophyta (golden-brown algae) and Rhodophyta (red algae). Each phylum consists of a single phylum branch, as is the case for Chlorophyta and Rhodophyta, or three separate branch, as is the case for Chromophyta (see Table 1.2). Each branch is itself divided into several classes. The number of classes may vary according to the criteria used by the different authors. This is particularly true for Rhodophyta, where complementary criteria to the pigmentary characteristics (nature of the starch, life cycle and reproduction, etc.) lead to the distinction of seven classes instead of one.

Phylum	Common pigment	Supernumerary pigments
Chlorophyta	Chlorophyll a	Chlorophyll b
Chromophyta	Chlorophyll a	– Chlorophylls c, e – Excess carotenoids (β-carotene, fucoxanthin, zeaxanthin, etc.)
Rhodophyta	Chlorophyll a	– Chlorophyll d – R or B Phycoerythrin – Phycocyanin – Allophycyanin

Table 1.1. *Pigment distribution according to the botanical phyla of microalgae (from Morançais* et al. *(2018))*

1.1.2.1. *Chlorophyta*

The phylum of Chlorophyta is characterized by the simultaneous presence of chlorophylls a and b. This group comprises 6,429 species and is divided into 11 distinct classes (Sexton and Lomas 2018) (see Table 1.2 where only the main ones are mentioned):

– the Chlorophyceae class with 3,653 species represents the main phylum taxonomic group. Microalgae belonging to the genera *Chlamydomonas*, *Volvox* and *Dunaliella* are the most representative members. The alga *Dunaliella* sp. is also valued in animal and human food (see sections 3.1 and 3.2);

– the Ulvophyceae class mainly includes macroalgae and some microscopic unicellular forms (Sexton and Lomas 2018);

– the Trebouxiophyceae class includes the genus *Chlorella*, a microalga valued in particular as a food supplement in human nutrition.

Phylum	Branch	Classes (number of species)
Chlorophyta (green algae)	Chlorophycophyta	– Chlorophyceae (3,653) – Ulvophyceae (1,725) – Trebouxiophyceae (794) – Prasinophyceae (105) – Mamiellophyceae (18)
Chromophyta (golden-brown algae)	Pheophycophyta	Pheophyceae (2,040)
	Chrysophycophyta	– Bacillariophyceae (11,000–100,000) (diatoms) – Chrysophyceae (670) – Xanthophyceae (450–600)
	Pyrrophycophyta	Dinophyceae (3,327)
Rhodophyta (red algae)	Rhodophycophyta	Rhodophyceae

Table 1.2. *Taxonomic distribution of algae according to the traditional classification enriched with the addition of secondary traits such as endosymbiotic origin plastid (based on Loir (2004) and Sexton and Lomas (2018))*

1.1.2.2. *Chromophyta*

The Chromophyta phylum is divided into three phylum branches, each of which is subdivided into several distinct classes (see Table 1.2). In the branch – of Pheophycophyta – there is one class, that of Phaeophyceae. Phaeophyceae include 2,040 species and are known as brown algae. They do not include unicellular forms, except for the presence of biflagellated spores during the reproductive cycle of these algae, the best-known members of which belong to the genera *Macrocystis*, *Laminaria* and *Fucus*.

In the Chrysophycophyta branch, there are three well-classified classes. Among them, the class of Bacillariophyceae is one of the most studied for its biological diversity and ecological importance. This class, known as diatoms, includes unicellular brown-yellow algae with sizes ranging from 2 μm to 1 mm (Loir 2004). The number of species of diatoms is estimated to be at least 11,000, but some authors estimate the number to be around 100,000 (Mann and Vanormelingen 2013). Diatoms are morphologically characterized by the presence of an external envelope of siliceous nature called a frustule. This name is derived from the Latin *frustulum*, which means "piece" or "small end" (Round *et al.* 1990). The frustule is a shell composed of two valves called the epivalve and hypovalve (see Figure 1.3). This structural element has different shapes and symmetries in different species.

The frustule is responsible for the dichotomous separation of diatoms into two distinct groups. When the latter is in the form of a disc or tube with radial symmetry, the diatoms are referred to as centric or central diatoms (see Figure 1.4). On the other hand, diatoms with a more or less elongated frustule and mainly showing bilateral symmetry are classified as pennate or pennal diatoms (see Figure 1.5).

The species *Haslea ostrearia* involved in the greening mechanism of oysters (see section 3.1) belongs to the latter group (see Figure 1.6). Diatoms are photosynthetic organisms, but some species living in light-poor environments are heterotrophic for carbon. These diatoms incapable of synthesizing chlorophyll represent less than 10 species belonging to the genera *Nitzschia* and *Hantzschia* (*Hantzschia achroma)* (Li and Volcani 1987).

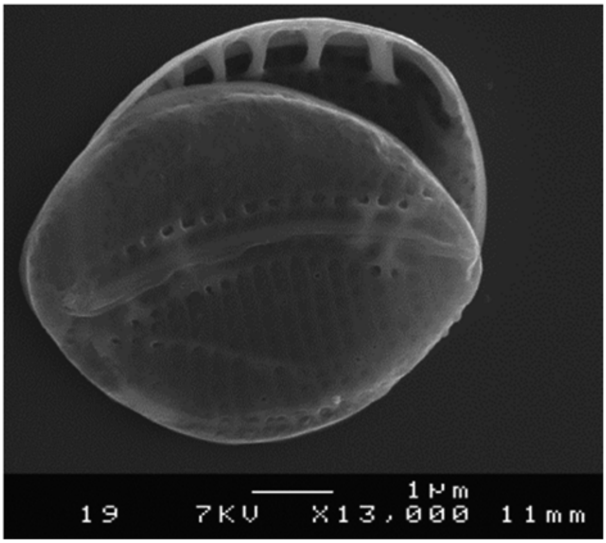


Figure 1.3. *Frustule (epivalve and hypovalve) of the diatom* Nitzschia *sp. visualized by a scanning electron microscope (SEM) (photo credit © Gaudin P., 2010)*

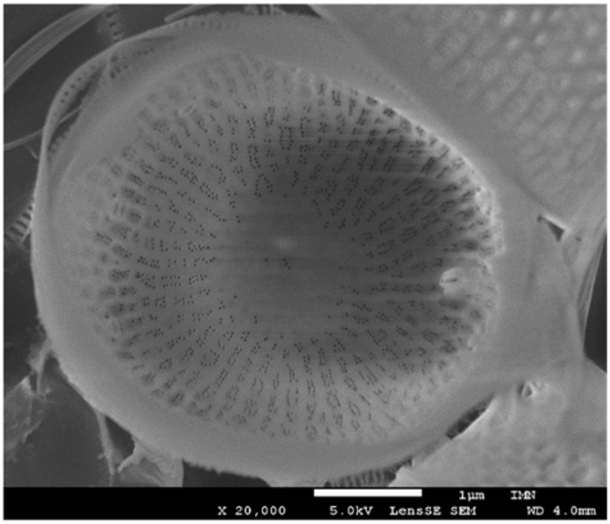


Figure 1.4. *Example of a central diatom* Skeletonema *sp. visualized by a scanning electron microscope (SEM) (photo credit © Petit A., 2010)*

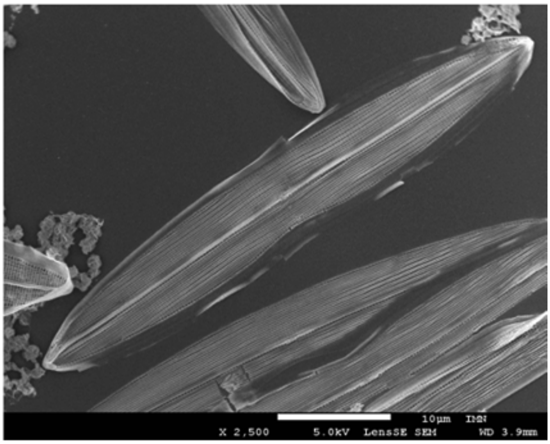


Figure 1.5. *Example of a pennate* Haslea ostrearia *diatom visualized by a scanning electron microscope (SEM) (photo credit © Petit A., 2010)*

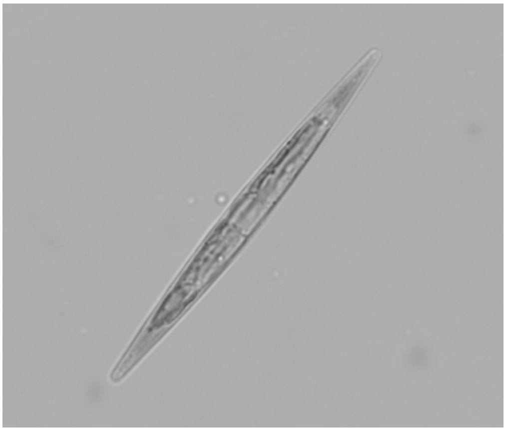


Figure 1.6. Haslea ostrearia*, pennate diatom, responsible for the greening of oysters (photo credit © Petit A., 2019). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

Chrysophyceae or golden yellow-brown algae include about 670 species. Although autotrophic for carbon, some of them are bacterivorous and have very different morphologies, ranging from filamentous to capsular or even spherical (Sexton and Lomas 2018). The main representatives belong to the genera *Dinobryon*, *Ochromonas* and *Phaeoplaca* or *Tisochrysis*.

The Xanthophyceae, known as yellow-green algae, are well listed in the Chromophyta phylum. They do not possess chlorophyll b, which is the pigmentary criterion shared by all Chlorophyta. The yellow color is due to the presence of an excess of yellow xantho phyllum (Sharma 1986). We find in this class the algae belonging to the genera *Vaucheria* and *Chloromeson*.

The Pyrrophycophyta branch is composed of several classes, the number of which varies according to the authors and some of which are considered today as obsolete. It should simply be remembered that this branch includes the class Dinophyceae (Dodge 1985), whose organisms, known as dinoflagellates, have a very particular position in the traditional classification. These organisms have often been considered as brown algae, but their evolutionary history based on mechanisms of secondary endosymbiosis suggests that they derive from an ancestor of the Rhodophyta type (Perez 1997; Nef 2019). Moreover, dinoflagellates have the particularity, in addition to an excess of β-carotene, of possessing a red-colored pigment, peridinin (Perez 1997). This specificity is at the origin of the red coloration of waters when dinoflagellates are present in large numbers in the environment. Apart from the above-mentioned characteristics, dinoflagellates present another particularity that makes their classification delicate. Indeed, this class constitutes a mixotrophic ensemble: 50% of the species are autotrophic for carbon, the others are heterotrophic for this element (Borowitzka 2018a, 2018b). They can therefore be linked to the animal kingdom or to the plant kingdom according to this trophic characteristic. These are organisms whose size fluctuates between 10 μm and 2 mm (Spector 1984). Many species of dinoflagellates are involved in the phenomenon of “red tides”. They mainly belong to the genera *Alexandrium*, *Dinophysis*, *Gymnodinium* and *Prorocentrum* (Faust and Gulledge 2002). They can produce toxins that affect invertebrates, fish and mammals. These toxins, the most well-known of which are DSP, for diarrhetic shellfish poisoning (see Figure 1.7), are at the origin of poisoning during the consumption of contaminated shellfish.

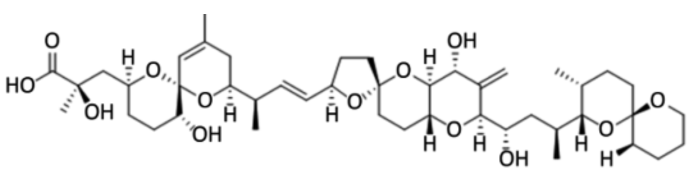


Figure 1.7. *Example of toxins produced by dinoflagellates (okadaic acid) (source: Grovel O.)*

1.1.2.3. *Rhodophyta*

On the basis of the pigment criterion, i.e. the specific presence of phycoerythrin as a supernumerary pigment, phylum has only one class (see Table 1.2). The use of additional criteria such as the nature of the starch stored in the cytoplasm, the presence of floridoside and the characteristics of the reproductive cycle led to the determination of seven classes, the main ones being Florideophyceae (6,793 species) and Bangiophyceae (196 species) (Sexton and Lomas 2018). The species *Porphyridium cruentum* (see Figure 1.8), an alga belonging to the latter class, is the subject of numerous evaluations, in particular as a cell factory for the production of exopolysaccharides, pigments or enzymes (super oxide dismutase) (see section 4.2).

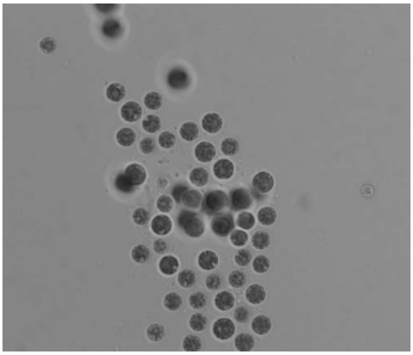


Figure 1.8. Porphyridium cruentum *(photo credit © Petit A., 2019). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

The traditional classification, although complex, classifies microalgae into three distinct groups: green algae, brown algae and red algae. This dichotomous division proves practical and useful for the valorization of this resource, whether for producers, processors or consumers.

1.1.2.4. *The green lineage and other clades*

Microalgae, like all organisms, can also be classified according to phylogenetic systematics. This approach, whose scientific interest is undeniable, is not easy to use in the framework of a valorization approach. Indeed, it is not based on the composition of pigments, molecules that can be valorized, but on genomic or morphological criteria. It is based, in particular, on the construction of the evolutionary history of algae from molecular criteria, such as DNA sequences coding for ribosomal subunits or those of ribosomic RNA. It is also based on the mechanisms of endosymbiosis at the origin of the algal cell and certain morphological criteria, such as the presence of a single flagellum (unikont) or a double flagellum (bicont) in unicellular forms of algae (microalgae or spores and gametes of macroalgae) (Lecointre and Le Guyader 2016). This approach leads to the isolation of certain groups of algae from others by associating them, for example, with unicellular organisms with animal affinity such as protozoa (Lecointre and Le Guyader 2016). In this new context, the dichotomous plant/animal division appears, according to some authors, outdated (Selosse 2006).

For phylogeneticists, algae do not constitute a homogeneous group from an evolutionary point of view. The use of molecular markers such as ribosomal DNA or ribosomal RNA has shown that these organisms do not constitute a monophyletic group. Within the eukaryotic phylogenetic tree, red and green algae are grouped in the "green line" group, which includes terrestrial plants (see Figure I.2). Dinoflagellates, microalgae initially grouped in the phylum of Chromophyta and the branch of Pyrrophycophyta (Spector 1984), are now listed within the Alveolobiontes or Alveolates group, which includes protozoa, such as ciliates, or sporozoan, or apicomplexa (Bhattacharya *et al*. 1992).

Diatoms, Haptophyta and Phaeophyceae, are associated with oomycetes (Aritzia *et al*. 1991) within the group of Heterokonta (Selosse 2006). Haptophyta, whose plastids have an endosym biotic rhodophyta origin and whose main characteristic is the presence of an organelle acting as a flagellum (haptonema) (Sexton and Lomas 2018), were thus isolated from their initial phylum. This new classification shows that the pigment character initially chosen to classify the algae was not a sufficiently relevant criterion to retrace the evolutionary history of the algae.

Nevertheless, this criterion is still relevant to distinguish the major botanical groups of algae that are being valorized, whether in the field of biotechnology or in that of human or animal nutrition.

1.1.3. *The special case of cyanobacteria (Cyanophyceae)*

Cyanobacteria have long been considered microalgae and classified as Cyanophyceae or "blue algae" or "blue-green algae". These organisms belong to the prokaryotic lineage, which is not the case for algae, which are all eukaryotic organisms. Cyanobacteria are the most important group of photosynthetic bacteria. The size of these organisms can vary between 1 µm and 10 µm. Cells can be isolated or form cell colonies of various shapes. In particular, they can produce filamentous excretions or trichomes. The cells are sometimes in close contact in a trichome, as is the case for the genus *Oscillatoria* (Lecointre and Le Guyader 2016). Colonies can also take on a spiral shape (see Figure 1.9).

Figure 1.9. Spirulina platensis *(*Arthrospira platensis*) (photo credit © Jubeau S., 2019). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

This is particularly the case of the species *Spirulina platensis*, which takes its name from this particular morphology. This species, renamed *Arthrospira platensis*, is currently valued as a food supplement in human nutrition (see section 3.2). Cyanobacteria constitute an important taxonomic group from the point of view of the number of species, although this number may vary according to the authors (Guiry 2012; Sexton and Lomas 2018). It is reported to be between 3,000 and 8,000 species, with the number of 8,000 being an estimate and not an exhaustive census (Guiry 2012) (see Table 1.3). In the traditional classification, cyanobacteria were listed in the phylum of Cyanophyta, the branch of Cyanophycophyta with a single class of Cyanophyceae. The phylogenetic classification revisited this group by integrating it into the field of eubacteria and dividing it into five different taxa (see Table 1.4) (Lecointre and Le Guyader 2016).

Cyanobacteria (Cyanophyceae or blue algae)	Number of species listed	Estimated number of species	Number total of species
According to Guiry (2012)	3,000	5,000	8,000
According to Sexton and Lomas (2018)	4,258	–	–

Table 1.3. *Assessment of the number of cyanobacteria species according to some authors*

Cyanobacteria	Some examples of species
Chroococcales	*Chroococcus membraninus* *Cyanobacterium stanieri* *Cyanobium gracile* *Cyanocystis violacea* *Dactylococopsis linearis* *Prochlorococcus marinus* *Synechocystis salina* *Gloeobacter violaceus*
Nostocales	*Anabaena variabilis* *Raphidiopsis mediterranea* *Nostoc commune*
Oscillatoriales	*Arthrospira platensis (Spirulina platensis)* *Oscillatoria princeps* *Spirulina labyrinthiformis* *Symploca atlantica* *Planktothrix agardhii*
Pleurocapsales	*Pleurocapsa minor* *Dermocarpella incrassata* *Chroococcopsis gigantea*
Stigonematales	*Stigonema tomentosum* *Nostochopsis lobatus* *Fischerella thermalis*

Table 1.4. *Taxonomic distribution of cyanobacteria according to phylogenetic classification (Lecointre and Le Guyader 2016)*

The cyanobacterium *Nostoc*, like *Arthrospira*, is used in human food (Chisti 2018).

1.2. Ecological features

Microalgae are present in many environments, whether aquatic, terrestrial or atmospheric. In the aquatic environment, marine microalgae can be distinguished from freshwater microalgae or freshwater algae. Marine and freshwater algae can live free in the water column or reside on the bottom, developing a thin layer called a biofilm. Seaweed in the water column is called phytoplankton, and seaweed on the bottom is called microphytobenthos. Phytoplankton can be subdivided into several categories according to the size of the organisms (see Table 1.5).

Category of phytoplankton	Size
Picoplankton	0.2 µm < x < 2 µm
Nannoplankton	2 µm < x < 20 µm
Microplankton	20 µm < x < 200 µm
Macroplankton	200 µm < x < 2,000 µm

Table 1.5. *Distribution of different categories of phytoplankton by size (from Iltis (1980))*

In fresh water, plankton is called potamoplankton. This name comes from the ancient Greek *potamos* or river, which etymologically means "river plankton". Whether marine or fresh water, microalgae can live in association with other organisms, such as cyanobacteria and fungi, to form a mixture called periphyton. Periphyton can colonize the surface of other organisms or inert media, such as rocks or submerged surfaces like plastics or metals.

1.2.1. *Marine microalgae*

Marine phytoplankton is responsible for half of the oxygen, the rest being generated by terrestrial plants and more particularly by the Amazonian forest (see Figure 1.10). It also acts as a climate regulator because of its capacity to sequester atmospheric CO_2. Phytoplankton also contributes to other biogeochemical cycles in the ocean. In particular, it participates in the nitrogen cycle. Cyanobacteria fix molecular nitrogen (N_2), and microalgae absorb other forms of available nitrogen, such as nitrates (NO_3^-), nitrites (NO_2^-) or ammonium (NH_4^+) (Nef 2019). It is also involved in the phosphorus and sulfur cycles. Dinoflagellates are among the main producers of dimethylsulfo niopropionate or DMSP, which can be transformed into dimethylsulfide (DMS), via the biological activity of certain organisms, before being converted into sulfuric acid in the atmosphere (Lovelock *et al.* 1972; Nef 2019). The production of sulfuric acid, an agent of cloud condensation, and of DMS that would modify the reflective capacity of clouds or albedo (Charlson *et al.* 1987) shows that the role of phytoplankton in climate regulation is not limited to its action as a carbon dioxide trap. Finally, the diatoms that represent the main group of microalgae in phytoplankton participate in the silicon cycle in the oceans through the synthesis of their frustule, which requires the contribution of silica. The organisms making up phytoplankton live in the photic zone, which is defined as the area of the ocean into which sunlight penetrates up to a limit value of 1%. Below this limit, one leaves the photic zone and enters the aphotic zone. However, the depth of the photic zone varies according to the turbidity of the water. In particular, it can go down to 200 m in the absence of turbidity. Phytoplankton is also the first link in the food chain. As such, it is considered to be the primary producer of the entire oceanic food web. Phytoplankton is mainly composed of cyanobacteria such as *Prochlorococcus marinus*, diatoms such as *Phaeodactylum tricornutum* and dinophyceae (Sardet 2013).

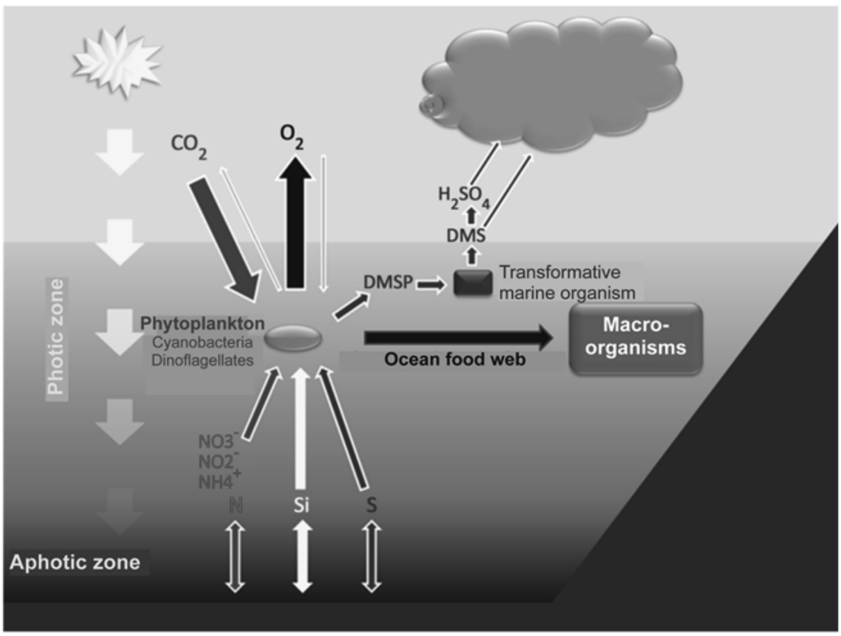


Figure 1.10. *Role of phytoplankton in the biogeochemical cycle of the ocean (source: Pouchus Y.-F.). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

Diatoms, the main group of microalgae in the marine environment, can be planktonic (phytoplankton) or benthic (microphytobenthos) (see Table 1.6). Some benthic species can be re-suspended by currents and support life in the open water. These species are called tychoplankton.

Species	Planktonic diatom	Benthic diatom	Tychoplanktonic diatom
***Chaetoceros* sp.**	+		
Odontella aurita	+		
Pseudo-nitzschia pungens	+		
Nitzschia angularis		+	
Nitzschia reversa		+	
Nitzschia bilobata		+	
Amphora inflexa		+	+

Table 1.6. *Some examples of planktonic, benthic and tychoplanktonic marine diatom species (from Loir (2004))*

1.2.2. *Microalgae in brackish and freshwater environments*

Microalgae are also present in brackish and fresh waters. Brackish waters are intermediate environments with respect to the marine and freshwater environment since the salinity varies between 1 and 10 g/L of salt (Loir 2014). In both types of environments, centric or pennate diatoms are found (see Table 1.7).

Species	Centric diatom	Pennate diatom
Melosira moniliformis	+	
Melosira nummuloides	+	
Fragilaria pulchella		+
Cocconeis scutellum		+
Anomoeonis sphaerophora		+
Diploneis didyma		+

Table 1.7. *Examples of common centric or pennate diatom species in brackish water (from Loir (2014))*

Some species can be found in both marine and brackish waters. This is particularly the case of the *Cocconeis scutellum* species, which is an organism that is very widespread on our coasts and which shows a very great adaptation to variations in salinity.

Freshwater diatoms are significantly less numerous than those living in the marine environment. Centered diatoms are represented in our rivers or lakes by only about 30 species (Loir 2014). Freshwater diatoms are generally benthic and can be found attached to mud, pebbles, submerged structures or even organic supports such as macrophyta, other diatoms or driftwood. The species *Melosira varians*, a diatom centered and very common in watercourses, lives attached to stones, algae or even submerged wood. This species can also be planktonic.

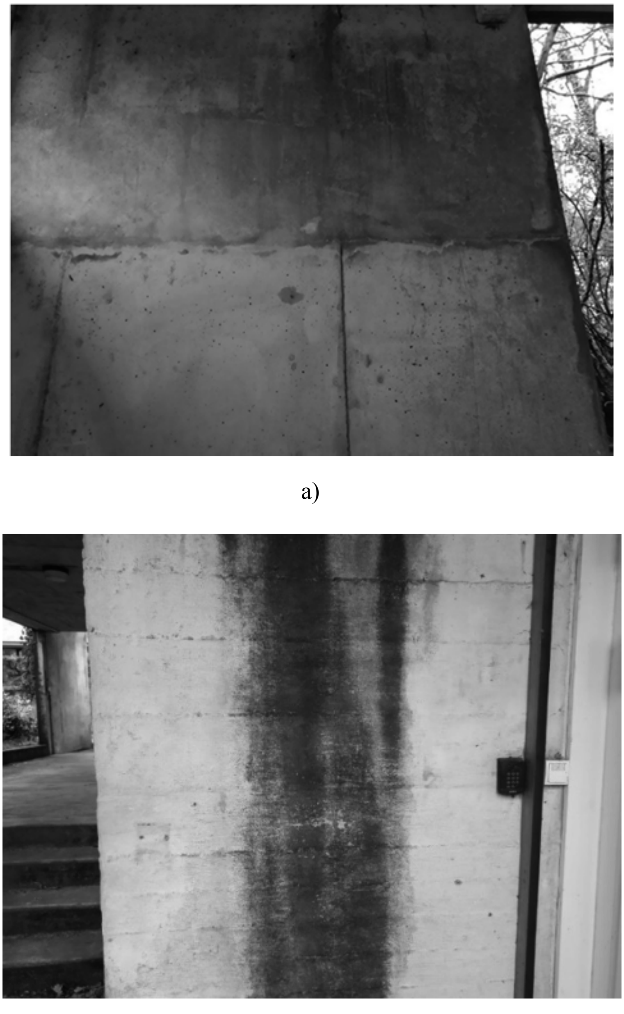
Apart from diatoms, fresh water contains many species of microalgae belonging to the group of Chlorophyta or related. These are mainly species belonging to the genera *Chlamydomonas*, *Pandorina*, *Volvox* and *Chlorella* (Greenhalgh and Ovenden 2009). Finally, there are also euglena belonging to the phylum of Euglenophyta, which derive by secondary endosymbiosis from the phylum of Chlorophyta (see Figure I.2).

Fresh water also contains cyanobacteria. Some species belonging to the genus *Arthrospira*, formerly *Spirulina*, have been consumed by people living near the lakes of the Mexico Valley (Sanchez *et al*. 2003). Cyanobacteria are also the cause of invasive phenomena or blooms in rivers, lakes or reservoirs, following the artificial enrichment of the environment with nutritive salts (Anderson *et al*. 2002). Other phenomena such as climate change predict the development of these cyanobacterial bloom phenomena in the future (Carey *et al*. 2012).

1.2.3. *Microalgae in terrestrial and aerial environments*

The presence of microalgae outside the aquatic environment is a well-known reality. Microalgae and cyanobacteria grow on wet fronts and fix the surrounding CO_2 while producing oxygen (see Figure 1.11(a) and (b)). In particular, they have replaced lichens on walls and tree trunks in highly polluted cities (Gudin 2013).

Recovering the conditions of the primitive earth in urban environments loaded with CO_2 and hydrogen sulfide, cyanobacteria and microalgae thus appear as potential depollution auxiliaries (Gudin 2013). Certain microalgae, such as *Porphyridium cruentum* nesting in damp churches, could, via the excretion of their purple pigment, phycoerythrin, be at the origin of the phenomenon of bleeding statues (Fleurence 2018). The atmosphere is not a normal habitat for microalgae. The algae present in the air are of various shapes and sizes (from 1 to 150 μm). The atmospheric algal flora is mainly composed of Chlorophyta, Chromophyta (diatoms, xanthophyceae) and cyanobacteria (Sharma and Rai 2011) (see Table 1.8).



a)

b)

Figure 1.11. *Examples of facades colonized by microalgae (photo credit © Fleurence J., 2019). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*

This biological diversity varies according to climatic conditions, geographical and topographical characteristics. For example, in tropical regions, the biodiversity of the aerial algal flora is richer than in other climatic regions. Cyanobacteria, in particular, dominate the tropical atmospheric flora. In contrast, Chlorophyta are the main organisms of this flora in temperate regions (Sharma and Rai 2011).

Species	**Cyanobacteria**	**Chlorophyta**	**Xanthophyceae (Chromophyta)**	**Diatoms (Chromophyta)**
Anabaena sp.	+			
Arthrospira sp.	+			
Nostoc sp.	+			
Spirulina sp.	+			
Chlamydomonas sp.		+		
Chlorella sp.		+		
Nannochloris sp.		+		
Microspora sp.		+		
Heterococcus sp.			+	
Vaucheria sp.			+	
Nitzschia sp.				+
Melosira sp.				+
Navicula sp.				+

Table 1.8. *Examples of genera constituting the algal aerial flora (from Sharma and Rai (2011))*

Microalgae and cyanobacteria are transferred to the layers of the atmosphere by a process called aerosolization, which transforms them into fine algal particles (see Figure 1.12). They are released from terrestrial or aquatic sources, as well as from vegetation or building facades and roofs by the action of wind and updrafts (see Figure 1.12).

Microalgae are varied unicellular organisms living in different environments or habitats. They show a great biological, biochemical, genetic and ecological adaptability. These properties are notably at the origin of their development both in the field of biotechnology and in that of nutrition.

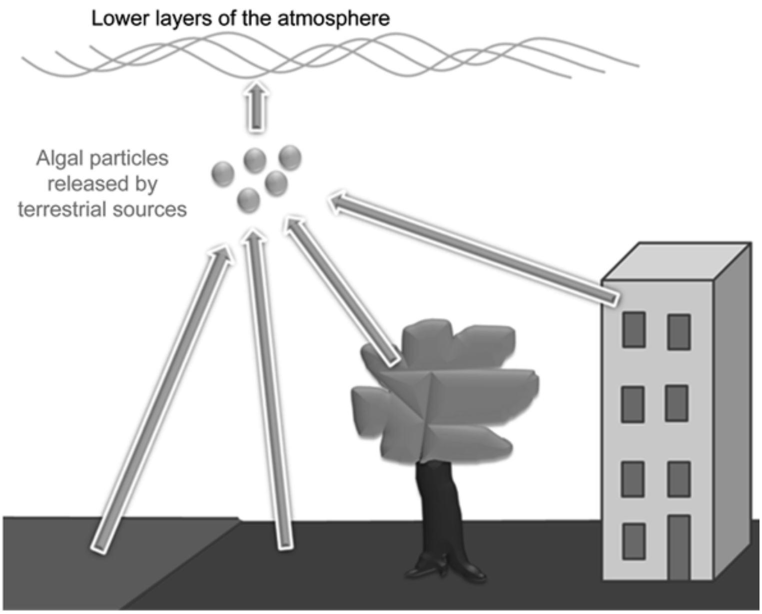


Figure 1.12. *Aerolization phenomenon causing the presence of algal particles in the layers of the atmosphere (source: Pouchus Y.-F., according to Sharma and Rai (2011)). For a color version of this figure, see www.iste.co.uk/fleurence/microalgae*