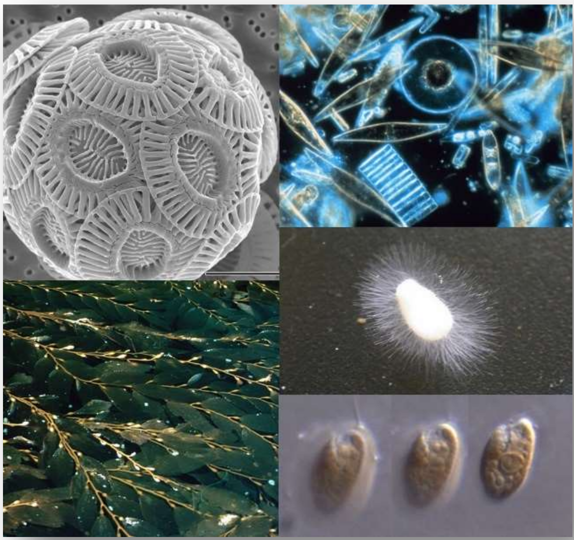
☞ *Chromista Kingdom*

The Chromista are a kingdom of unicellular and multicellular eukaryotic organisms that includes taxa historically regarded as protozoans (such as foraminiferans, radiolarians, and ciliates), fungi-like organisms (including oomycetes and labyrinthulomycetes), and algae (such as brown algae and diatoms).

Traditionally, Chromista has been considered a polyphyletic group—meaning that its members do not all share a single common ancestor exclusive to them—but rather a collection of eukaryotes that share similar features in their photosynthetic organelles (chloroplasts). Typically, Chromista exhibit one or both of the following characteristics:

- **Plastids with four membranes:** Their plastids contain chlorophyll c and are surrounded by four membranes.
- **Specialized cilia:** They have cilia bearing rigid, tubular hairs that are either tripartite or bipartite.



Chromista collage (Wikipédia)

According to the traditional view, if the common ancestor of these organisms already possessed chloroplasts derived via endosymbiosis with a red alga, then all non-photosynthetic Chromista are thought to have secondarily lost their photosynthetic ability.

This group includes a diverse array of organisms, ranging from algae to malaria parasites (Plasmodium). Molecular evidence has long supported the hypothesis that the plastids of chromists originated from red algae through a single secondary endosymbiotic event. In contrast, plants acquired their plastids from cyanobacteria via primary endosymbiosis—a process that resulted in plastids being enclosed by two additional membranes, forming a four-membrane envelope. This extra membrane system enabled the integration of numerous membrane proteins crucial for transporting molecules into and out of the organelles.

It should be noted, however, that recent phylogenomic studies have questioned the monophyly of Chromista and suggest a more complex evolutionary history. Many groups traditionally classified as Chromista—such as alveolates, stramenopiles, and Rhizaria—are now frequently placed within the SAR supergroup (Stramenopiles, Alveolates, and Rhizaria). Likewise, the idea of a single secondary endosymbiotic event with red algae is now viewed as an oversimplification, with some evidence pointing toward multiple acquisitions or losses of photosynthetic capacity over time.

Here, we focus on the chlorophyll-containing organisms within the Chromista—the Chromophytes—which is a paraphyletic evolutionary grade grouping all Chromista that possess chlorophyll c.

2.1 Diatoms (Bacillariophyceae)

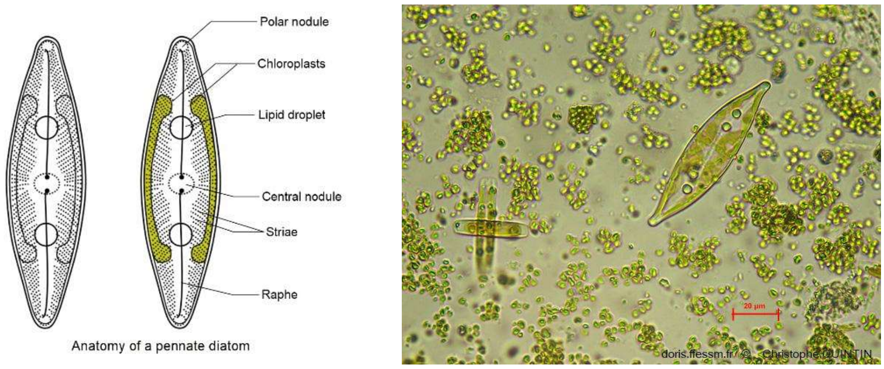


Figure 4.1: Diatom structure (left) and microscopic observation (right).

Diatoms are unicellular organisms that can exist as solitary cells or in colonies with shapes like ribbons, fans, zigzags, or stars. Their cells range from 2 to 200 micrometers in size and are surrounded by a unique silica cell wall called a frustule, which gives them a structural coloration—earning them the nicknames "jewels of the sea" and "living opals." Like plants, diatoms convert light into chemical energy through photosynthesis, though their chloroplasts originated through various evolutionary events.

Their yellowish-brown chloroplasts—the sites of photosynthesis—are typical of heterokonts, featuring four membranes and fucoxanthin pigment. While most cells lack flagella, male gametes of centric diatoms do have them, complete with the characteristic mastigonemes.

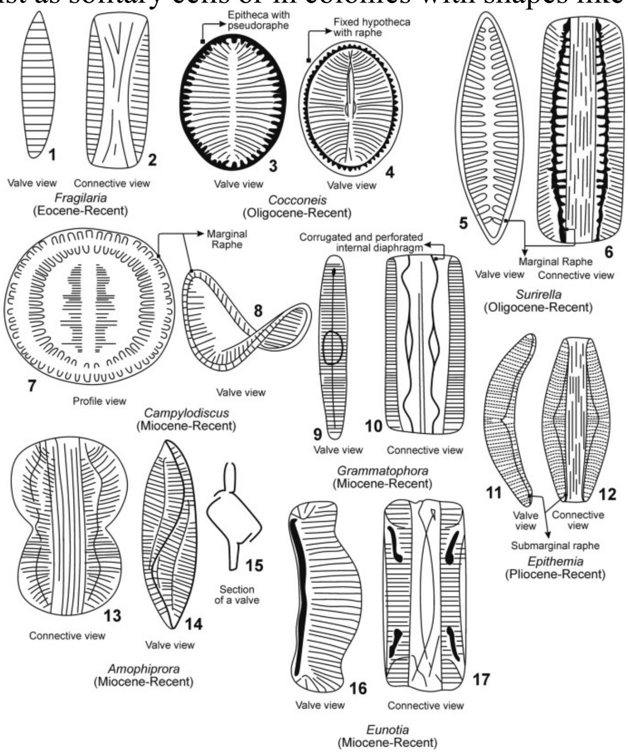


Figure 4.2: Diatoms different forms

2.1.1 Ecology

Found in oceans, waterways, and soils worldwide, living diatoms account for a significant portion of Earth's biomass. They produce roughly 20–50 percent of the oxygen generated on the planet each year, absorb over 6.7 billion tons of silicon annually from their aquatic environments, and make up nearly half of the organic matter in the oceans. The shells of dead diatoms can accumulate to thicknesses of up to 800 meters on the seafloor, and the entire Amazon basin is fertilized annually by 27 million tons of diatom shell dust carried by transatlantic winds from the African Sahara—much of it originating from the Bodélé Depression, which was once a system of freshwater lakes.

The Rhopalodiaceae family also harbors a cyanobacterial endosymbiont known as a spheroid body. Although this endosymbiont has lost its photosynthetic ability, it retains the capacity for nitrogen fixation, enabling the diatom to convert atmospheric nitrogen into a usable form. Other diatoms in symbiosis with nitrogen-fixing cyanobacteria include members of the genera Hemiaulus, Rhizosolenia, and Chaetoceros.

Diatoms are widely used to monitor both past and present environmental conditions and are common indicators in water quality studies. Diatomite—sedimentary rock composed of fossilized diatom shells—is found in the Earth's crust. This soft, silica-rich rock easily crumbles into a fine powder, with typical particle sizes ranging from 10 to 200 µm. Diatomite is utilized for various purposes, including water filtration, as a mild abrasive, in cat litter, and as a dynamite stabilizer.

2.1.2 Life cycle

Diatoms have an essentially diplontic life cycle. The diploid cells multiply by mitosis for several months or even years. Each of the parent cell's valves becomes the epitheca for a daughter cell, which then secretes the corresponding hypotheca. As a result, one of the two daughter diatoms is smaller than the original cell while the other remains the same size. Consequently, with successive divisions, smaller diatoms appear, and one lineage of descendants decreases in size with each generation (figure).

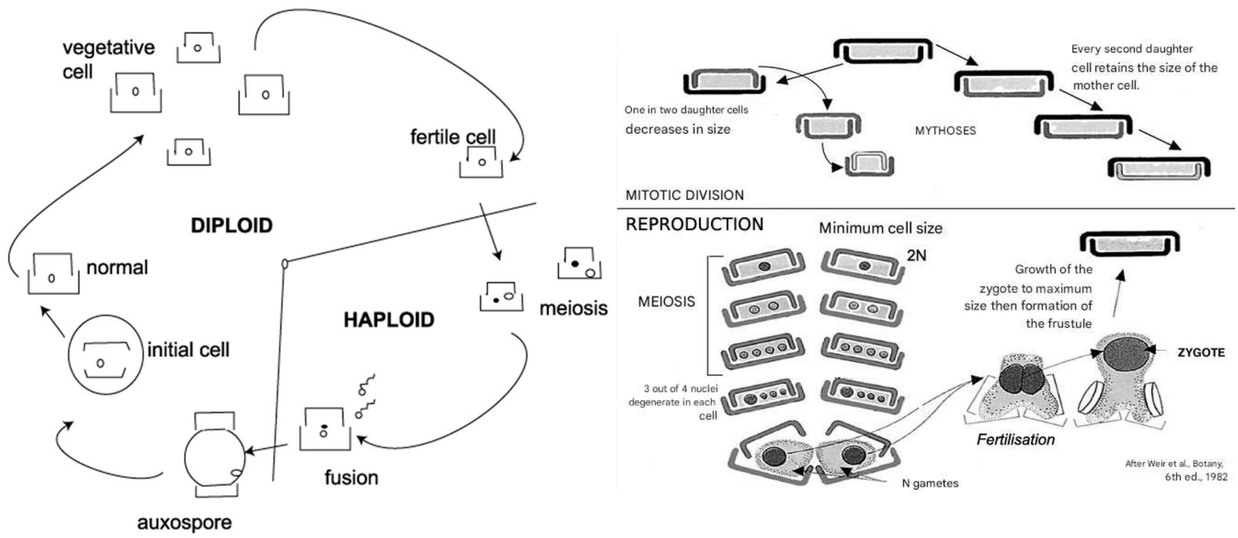


Figure 4.3: Diatoms life cycle.

This reduction does not continue indefinitely. Once the cells reach a threshold—approximately 30% of their original size—they undergo meiosis and produce gametes (with the male gamete being the only flagellated cell in the cycle), whose cell walls lack a silica frustule. The zygote formed by the fusion of the gametes (the auxospore) then grows to the maximum size characteristic of the species or population before forming a new frustule (figure).

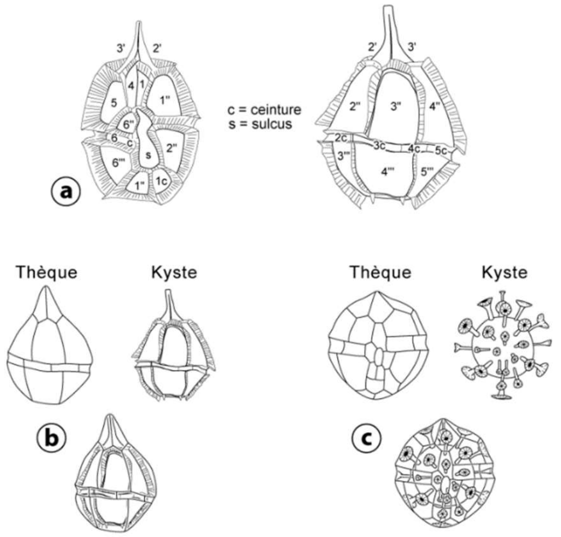
2.2 Dinophyta (Dinoflagellate)

Dinoflagellates are a monophyletic group of unicellular eukaryotes that make up the phylum Dinoflagellata, currently classified within the kingdom Chromista. They are primarily marine plankton, though they are also common in freshwater habitats. Their populations vary based on sea surface temperature, salinity, and depth. While many dinoflagellates are photosynthetic, a large fraction are mixotrophic, combining photosynthesis with the ingestion of prey through phagotrophy and myzocytosis.

Some dinoflagellates produce resting stages, known as dinoflagellate cysts or dinocysts, as part of their life cycle. This occurs in 84 of the 350 described freshwater species and in just over 10% of known marine species.

2.2.1 Morphology

In many species, the cell is protected by a theca composed of rigid cellulose plates embedded with silica. The flagella rest in two superficial grooves: a transverse (or equatorial) groove called the "cingulum" and a longitudinal groove called the "sulcus" (from the Latin cingulum, meaning "belt," and sulcus, meaning "groove"). The equatorial groove divides the cell into an upper part (the epicone) and a lower, posterior part (the hypocone or hyposome). When a theca is present, these two parts are respectively referred to as the epitheca and the hypotheca.



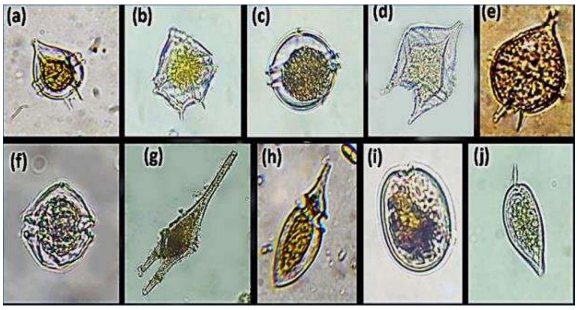


Figure 4.4: Microscopic Observation : (a) *Protoperidinium granii*; (b) *P. leonis*; (c) *P. minutam*; (d) *P. claudicans*; (e) *P. cerasus*; (f) *Alexandrium fundyense*; (g) *Ceratium furca*; (h) *Oxyphysis oxytoxoides*; (i) *Prorocentrum lima and* (j) *P. gracile*

Figure 4.5: a) Diagram of a fossil dinoflagellate cyst; panels b-c: Cyst paratabulation reflecting (b) directly or (c) indirectly the tabulation of the theca (after W.A.S. SARJEANT, adapted by E. MASURE).

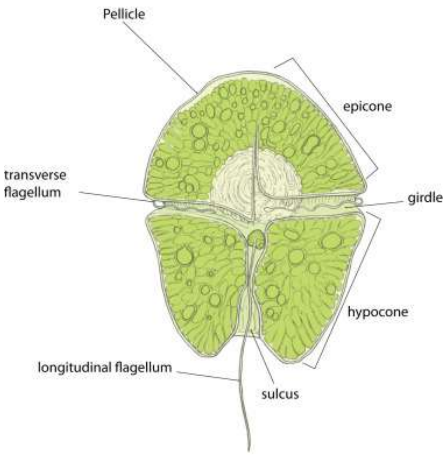


Figure 4.5d: Dinoflagellate structure

2.2.2 Ecology

In terms of species number, dinoflagellates are one of the largest groups of marine eukaryotes, although they are significantly less numerous than diatoms. Some species are endosymbionts of marine animals and play an important role in coral reef biology. Other dinoflagellates are non-pigmented predators of other protozoa, and some forms are parasitic (for example, Oodinium and Pfiesteria). Recent estimates suggest there are a total of 2,294 living dinoflagellate species, including marine, freshwater, and parasitic types.

A rapid accumulation of certain dinoflagellates can cause a visible discoloration of the water, commonly known as a red tide (a harmful algal bloom), which may lead to seafood poisoning if humans consume contaminated seafood. Some dinoflagellates also exhibit bioluminescence, emitting mainly blue-green light; as a result, parts of the ocean can light up with a blue-green glow at night.

2.2.3 Life Cycle

Dinoflagellates generally have a monogenetic, haplontic life cycle that typically involves asexual reproduction through mitosis. More complex life cycles occur, particularly among parasitic dinoflagellates.

Sexual reproduction also takes place, although it is observed in only a small percentage of dinoflagellates. This sexual process involves the fusion of two individuals (caryogamy) to form a zygote, which may remain motile—a typical trait of dinoflagellates—and is then called a planozygote. The zygote can subsequently form a resting stage in the form of a dinoflagellate cyst or dinocyst. After (or before) the cyst germinates, the newly hatched cell undergoes meiosis to produce new haploid cells. Additionally, dinoflagellates appear capable of carrying out multiple DNA repair processes that address various types of DNA damage.

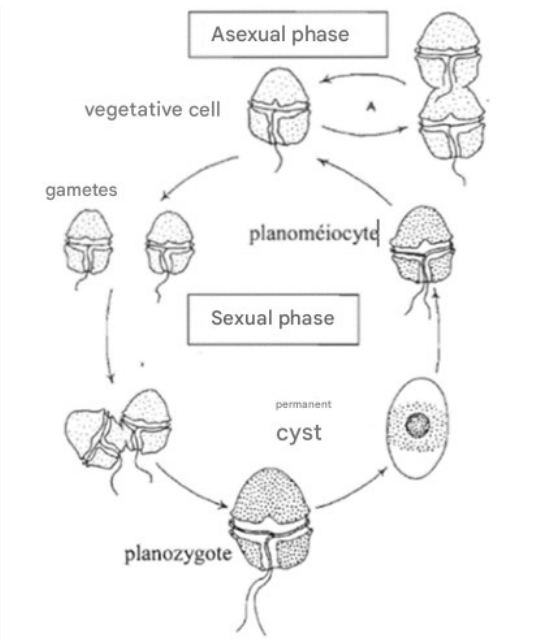


Figure 4.6: Cycle de vie simplifié des dinoflagellés (Fritz et al., 1989)

2.3 Haptophyta

Haptophytes constitute a division belonging to the phylum **Haptophyta**, classified within the kingdom **Chromista**. This diverse group of unicellular photosynthetic organisms plays a major ecological role in aquatic ecosystems. They are characterized by the presence of a unique appendage distinct from flagella, the **haptonema**—a filamentous structure containing microtubules. Its size varies by species, and it is involved in substrate adhesion, particle movement, and even prey capture. Recent research also suggests that the haptonema may have a role in environmental sensing.

Their photosynthetic apparatus primarily contains chlorophylls **a** and **c**, along with **xanthophylls** such as **fucoxanthin**, For carotenoids, they have beta-, alpha-, and gamma-carotenes. Like diatoms and brown algae, they have also fucoxanthin, an oxidized isoprenoid derivative that is likely the most important driver of their brownish-yellow colorwhich gives them a golden-brown hue and optimizes light absorption in marine environments. Some species even possess specific variants of these pigments adapted to different light conditions.

Notably, haptophytes—especially the **coccolithophores**—play a crucial role in the oceanic carbon cycle by sequestering carbon dioxide in the form of **calcium carbonate**. Their contribution to primary productivity and climate regulation makes them a group of major interest in oceanography and biogeochemistry.

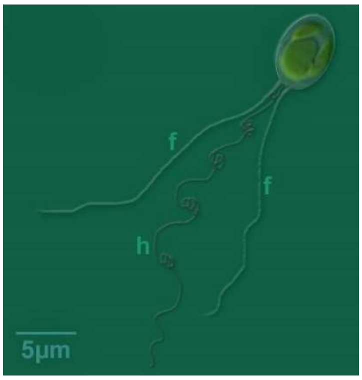


Figure 4.7: Example of the shape and length of a haptonema (h) in an alga from the Haptophyta division, with some helical windings and, here, between two flagella (f). Many other sizes and shapes of haptonemes are found in the algae of this class. In some species, it is vestigial or do not exist.

The current number of species is estimated to be around 500, many of which are characterized by calcite scales (calcium carbonate) that cover the cell (coccoliths). Many species are tropical, a few species inhabit freshwater, and numerous fossil groups exist.

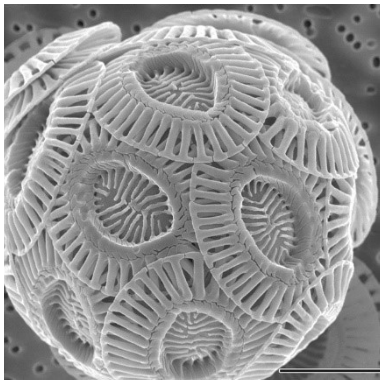


Figure 4.8: *Emiliania huxleyi* - single-celled marine phytoplankton that produce calcium carbonate scales (coccoliths). A scanning electron micrograph of a single coccolithophore cell.

2.3.1 Life cycle

- ☞ Haptophytes generally have a haplodiplophasic life cycle, alternating between haploid and diploid phases.
- ☞ Asexual reproduction usually occurs through mitotic cell division.
- ☞ Sexual reproduction involves the formation of haploid gametes that fuse to form a diploid zygote.
- ☞ The zygote can then undergo cell division to form haploid cells, thereby renewing the cycle.

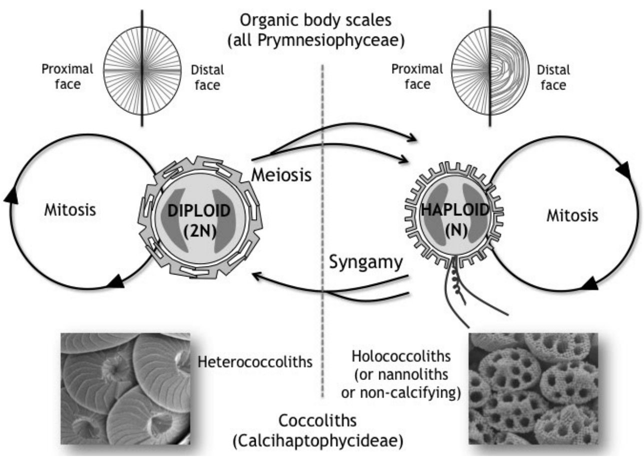


Figure 4.9: Life cycle of Coccoliths.

2.4 Cercozoa

Cercozoans belong to the kingdom Chromista, which encompasses a variety of protists, including certain algae and other microorganisms.

2.4.1 Morphology

Cercozoans exhibit a wide range of morphologies, including:

- **Amoeboid Forms**: Many cercozoans are amoeboid, extending filose (thread-like) pseudopodia for movement and feeding.
- **Flagellated Forms**: Some possess one or more flagella, enabling them to swim in aquatic environments.
- **Testate Amoebae**: Certain cercozoans, such as euglyphids, produce shells (tests) composed of siliceous scales or plates, provid ing structural protection.
- **Chlorarachniophytes**: This subgroup contains chloroplasts acquired from ingested green algae, surrounded by four membranes and retaining a vestigial nucleus (nucleomorph), offering insights into endosymbiotic events.

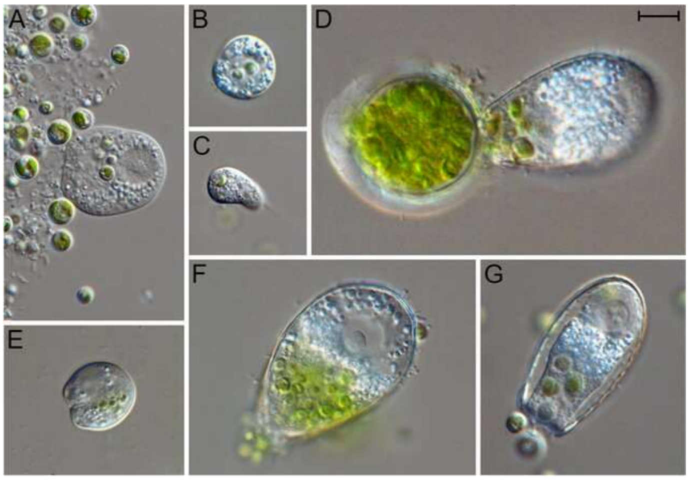


Figure: Selected images of algivorous Cercozoa and their prey.

2.4.2 Ecology

Cercozoans are ecologically significant across various environments:

- **Soil Ecosystems**: They are abundant in temperate soils, accounting for about 30% of identifiable protozoan DNA in arid or semi-arid soils and 15% in more humid soils, playing a crucial role in nutrient cycling.
- **Aquatic Environments**: Cercozoans are present in both marine and freshwater ecosystems, contributing to microbial diversity and functioning as predators of bacteria and other microorganisms.
- **Phyllosphere**: On plant leaf surfaces, cercozoans, particularly sarcomonads, influence bacterial community composition, affecting plant health and ecosystem dynamics.

2.4.3 Life Cycle

Cercozoans primarily reproduce asexually through binary fission, where a single cell divides into two identical daughter cells. Some species can form cysts, allowing them to survive unfavorable environmental conditions. Sexual reproduction has not been widely documented among cercozoans and may be absent or rare within this group.

2.5 Phaeophyceae (brown algae)

Brown algae, also known as Phaeophyceae, are a class of algae belonging to the phylum **Ochrophyta** (kingdom Chromista). They are algae that primarily use chlorophyll c, combined with a brown pigment, fucoxanthin, as their light-harvesting pigment. Their size ranges from microscopic scale to several tens of meters.

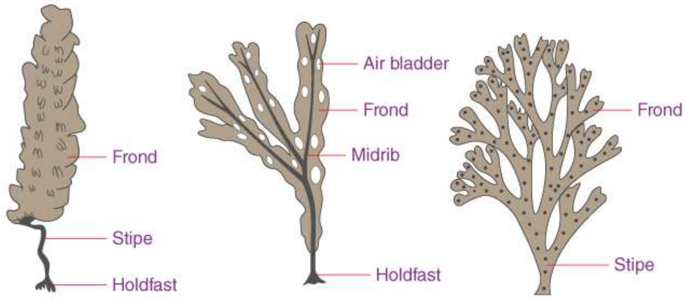


Figure 4.10: From the left -(1) Brown algae (2) *Laminaria* (3) *Fucus* (iii) *Dictyota*.

The term "brown algae" is also used for brown-colored filamentous algae that should in no case be confused with the Phaeophyceae. In reality, these are colonies of cyanobacteria, notably responsible for bacterial flocs (also known as brown slime in English-speaking countries).

There are about 1,500 species of Phaeophyceae, and they are abundant in temperate and cold seas.

2.5.1 Morphology

The general morphology of the Phaeophyceae is that of algae, meaning that they are aquatic organisms that use photosynthesis and are unable to support themselves out of water. Their color ranges from olive green to brown.

Like other algae, the Phaeophyceae do not have tissues as well differentiated as those in vascular plants, nor do they possess parts that can be described as roots, stems, or leaves. The entire developed organism is called a thallus. Nevertheless, brown algae, more so than other algae, have developed specialized organs (see figure):

- Holdfasts composed of haptera (rhizoids) that enable anchorage
- Pneumatocysts (floaters) that keep the algae near the surface
- A stipe (false stem), which is very well developed in Laminariales and shows an initial tissue differentiation that allows for the transfer of nutrients
- Fronds (or blades) that resemble leaves

Figure 4.11: Le *Fucus vesiculosus* produit de nombreux pneumatocystes (vésicules remplies de gaz) pour augmenter sa flottabilité.

2.5.2 Ecology of Phaeophyceae

Brown algae, primarily marine, occupy a variety of habitats ranging from seashores to depths of several tens of meters. They are abundant in temperate and cold coastal areas, although they can also be found in tropical and subtropical waters. Brown algae are often dominant elements in marine ecosystems, playing a crucial role as primary producers and providing habitat for numerous species.

Some brown algae, such as Sargassum, can reach great sizes and form distinct habitats, like kelp forests. They are also important in estuaries, where they withstand significant variations in salinity, temperature, and light. Despite their predominance in temperate and cold seas, some brown algae have even managed to colonize freshwater under rare circumstances.

Brown algae are rich in carbohydrates and iodine, with certain species capable of accumulating high concentrations of iodide in seawater. The Laminariales, in particular, are very efficient iodine accumulators and have a significant impact on atmospheric chemistry. When under stress, they rapidly release large quantities of iodine into the atmosphere, thus playing a role in detoxifying ozone and other oxidants.

2.5.3 Reproduction

Multicellular algae exhibit various developmental cycles. Brown algae have two types of sporocysts (a sporocyst is a plant structure that produces and contains spores) that follow either the pathway of sexual reproduction or that of asexual reproduction.

- ☞ The first type, the plurilocular sporocyst, contains several stem cells producing diploid zoospores (2n chromosomes) that subsequently germinate into sporophytes. This is the asexual multiplication pathway.
- ☞ The second type, the unilocular sporocyst, consists of a single stem cell which, through meiosis, produces four haploid zoospores (n chromosomes) that germinate into gametophytes. This represents the pathway of sexual reproduction.
- ☞ In detail, the most complex life cycles are characterized by an alternation of generations. Alternation of generations means there is a succession of haploid (n) and diploid (2n) forms. This term applies only when the cycles involve multicellular haploid and diploid stages. Brown algae encompass various types with specific reproductive cycles.

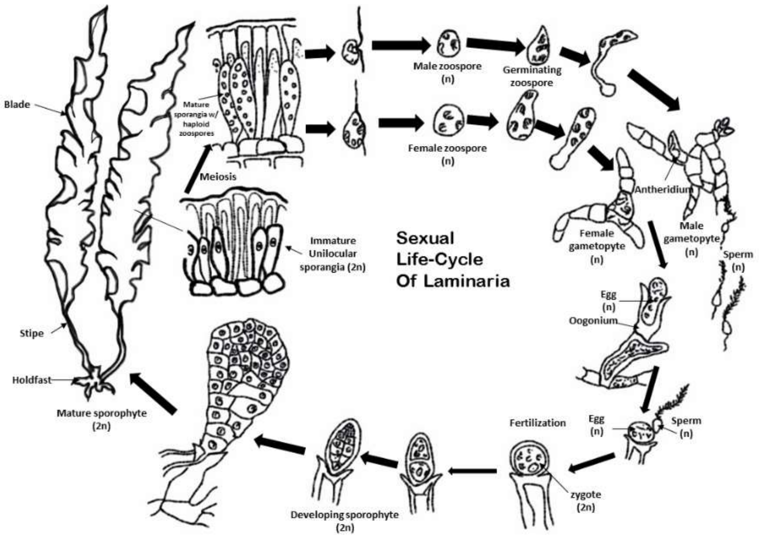


Figure 4.12: Sexual life-cycle of *Laminaria* sp.

Example: Life cycle of *Laminaria* sp.

a. First, the cycle begins with a diploid (2n) individual called the sporophyte.
b. At the beginning of spring, most of the growth is completed, and the cells at the surface become sporocysts. These are structures that produce and contain forms of asexual reproduction.
c. Next, the sporocysts produce zoospores by meiosis. The zoospores are structurally identical, but about half will develop into male gametophytes and the other half into female gametophytes.
d. The male gametophyte releases male gametes, or anthérozoids, while the female gametophyte releases female gametes, or oospheres. These gametes are haploid (n) organisms.
e. The oospheres remain on the female gametophyte and release a chemical substance that attracts anthérozoids of the same species, thereby increasing the fertilization rate in the ocean, where water tends to disperse them and make fertilization very difficult.
f. Finally, fertilization occurs when a male gamete fuses with an oosphere, forming a zygote—a diploid (2n) organism.
g. To conclude, the zygote develops into a new sporophyte and restarts the life cycle, forming a continuous loop. In this case, the two generations are heteromorphic, meaning that the sporophyte and gametophyte have different structures and do not resemble each other. Other algae exhibit an alternation of isomorphic generations, where the sporophyte and gametophyte appear morphologically identical but do not have the same number of chromosomes.