Physiology and Cultivation of Algae and Cyanobacteria

1.

Definition

- Algae formal tax. standing, polyphyletic origin, artificial assemblage of O_2 evolving photosynthetic organisms
- Algae *vs.* Plants

the same storage compounds, similar defence strategies against predators & parasites

Plants

•hi degree of differentiation
•repr. organs surrounded by jacket of sterile cells
•multicell. embryo remains developmentally & nutrit. independent on parents
•meristems on root/shoot apices
•digenetic life cycles with alterations betw. hapl. gametophyte & dipl. sporophyte

Algae

•don’t have roots, stems, leaves, not well defined vasc. tissue
•don’t form embryo
•mono- & digenetic life cycles
•occur in dissimilar forms (micro algae, macro a. multicellular, colonies, branched,…)
•less complexity of the thalli
•hi diversity 0.2 – 60m
ecology & habitats
reserve & structural polysaccharides
evolutionary origin
•1 – 10 mil. species
•½ primary production in biosphere

Classification

- under constant revision

(Van Den Hoek *et* al. 1995)

TABLE 1.1
Classification Scheme of the Different Algal Groups

Kingdom	Division	Class
Prokaryota eubacteria	Cyanophyta	Cyanophyceae
	Prochlorophyta	Prochlorophyceae
Eukaryota	Glaucophyta	Glaucophyceae
	Rhodophyta	Bangiophyceae
		Florideophyceae
	Heterokontophyta	Chrysophyceae
		Xanthophyceae
		Eustigmatophyceae
		Bacillariophyceae
		Raphidophyceae
		Dictyochophyceae
		Phaeophyceae
	Haptophyta	Haptophyceae
	Cryptophyta	Cryptophyceae
	Dinophyta	Dinophyceae
	Euglenophyta	Euglenophyceae
	Chlorarachniophyta	Chlorarachniophyceae
	Chlorophyta	Prasinophyceae
		Chlorophyceae
		Ulvophyceae
		Cladophorophyceae
		Bryopsidophyceae
		Zygnematophyceae
		Trentepohliophyceae
		Klebsormidiophyceæ
		Charophyceae
		Dasycladophyceae

Occurrence & distribution

Aquatic

- almost everywhere (from freshwater spring to salt lakes)
- tolerance of wide range of pH, temp., turbidity, O_2 & CO_2 conc.
- **planctonic**
      - » unicellular, suspended throughout lighted regions of all water (inc. polar ice)
- **benthic**
      - » within sediments
      - » limited to shallow areas (because of rapid attenuation of light with depth)
      - » attached to stones – **epilithic**, on mud/sand – **epipelic**
      - » on other algae/plants – **epiphytic**, on animals – **epizoic**
   - marine benthic – after habitat
      - **supralitoral** – above high-tide level within reach wave spray
      - **intertidal** – exposed to tidal cycles
      - **sublitoral** – from extreme low-water to cca 200m deep
- ocean – 71% of earth surface, more than 5000 spec. of planktonic algae
   - **phytoplankton**
      - » base of marine food chain
      - » produce 50% of O_2 we inhale - life
      - » death – blooms – too large populations (decrease water transparency, prod. toxins & poisons)
   - **kelps**
      - » giant algae – temperate **pelagic** marine environment, till 60m submerged forests
      - » also beneath polar ice sheet
      - » can survive at very low depth
   - record of 268m u.s.l. – dark blue red algae (blue-green ligh, 0.0005% of surface intensity)
      - » have accessory pigments, channel the energy to chl *a*
- accessory & protective pigments – give algae wide variety of colors <> names

Occurrence & distribution

Freshwater phytoplankton & benthic algae

- » base of aquatic food chain
- » not exhibit size range of marine relatives

Subaerial

- » life on land
- » tree trunks, animal fur, snow, hot springs, desert rocks
- » activity – convert rock > soil
  – to minimize soil erosion & increase water retention & nutrient availability for plants

Symbiosis

- lichens, corals
  - » to survive in environments that they could not alone

TABLE 1.2
Distribution of Algal Divisions

Division	Common Name	Habitat			
		Marine	Freshwater	Terrestrial	Symbiotic
Cyanophyta	Blue-green algae	Yes	Yes	Yes	Yes
Prochlorophyta	n.a.	Yes	n.d.	n.d.	Yes
Glaucophyta	n.a.	n.d.	Yes	Yes	Yes
Rhodophyta	Red algae	Yes	Yes	Yes	Yes
Heterokontophyta	Golden algae Yellow-green algae Diatoms Brown algae	Yes	Yes	Yes	Yes
Haptophyta	Coccolithophorids	Yes	Yes	Yes	Yes
Cryptophyta	Cryptomonads	Yes	Yes	n.d.	Yes
Chlorarachniophyta	n.a.	Yes	n.d.	n.d.	Yes
Dinophyta	Dinoflagellates	Yes	Yes	n.d.	Yes
Euglenophyta	Euglenoids	Yes	Yes	Yes	Yes
Chlorophyta	Green algae	Yes	Yes	Yes	Yes

Note: n.a., not available; n.d., not detected.

Structure o thallus

Unicells & unicell colonial algae

- solitary cells, unicells with/w-out flagella, motile (*Ochromonas*)/non-motile (*Nannochloris*)

- **colony**
  - aggregates of several single cells held together ±organized
  - grow – cell division
  - each cell can survive solely
- **coenobium**
  - colony with number of cells & arrangement determined at the time of origin *(e.g. Volvox* – motile, *Pediastrum* – non-motile)

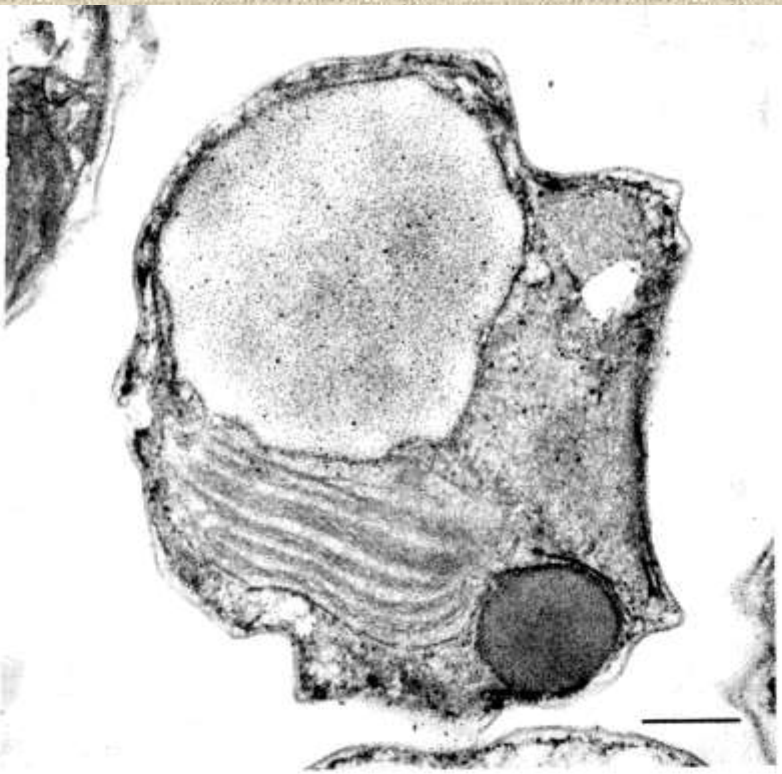


FIGURE 1.1 Transmission electron micrograph of *Nannochloropsis* sp., non-motile unicell. (Bar: 0.5 μm.)

FIGURE 1.2 *Ochromonas* sp., motile unicell. (Bar: 4 μm.)

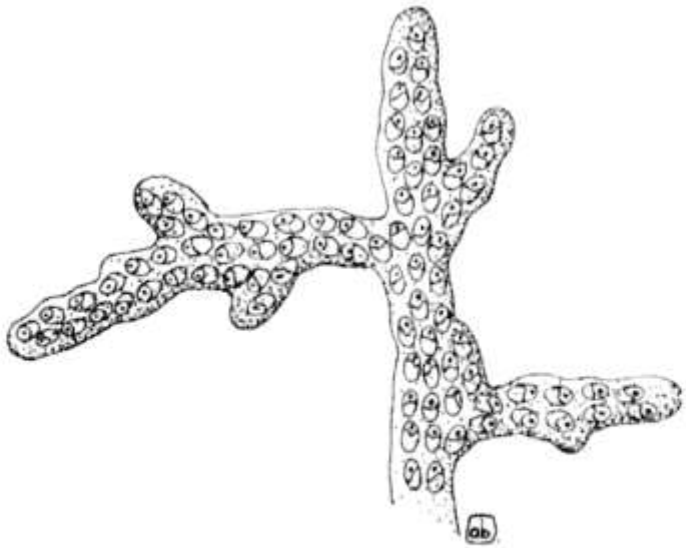


FIGURE 1.3 Non-motile colony of *Hydrurus foetidus.*

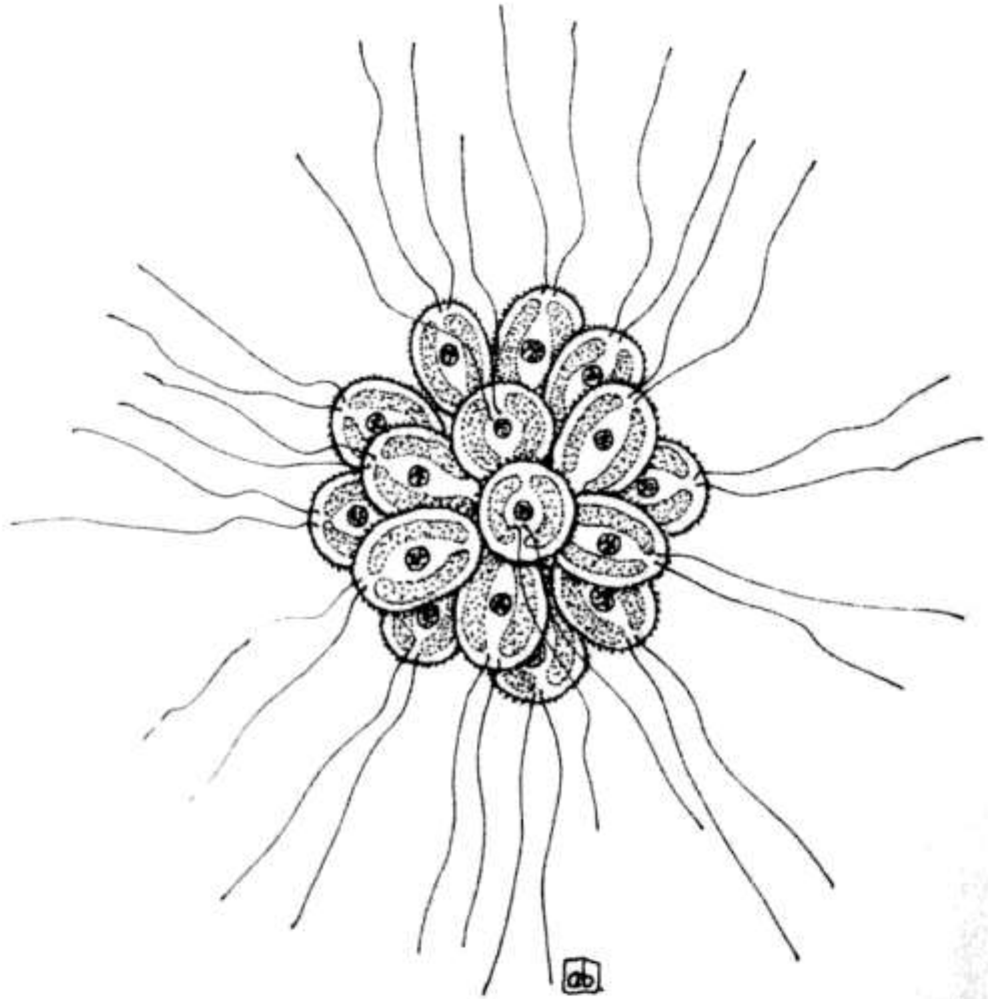


FIGURE 1.4 Free-swimming colony of *Synura uvella.*

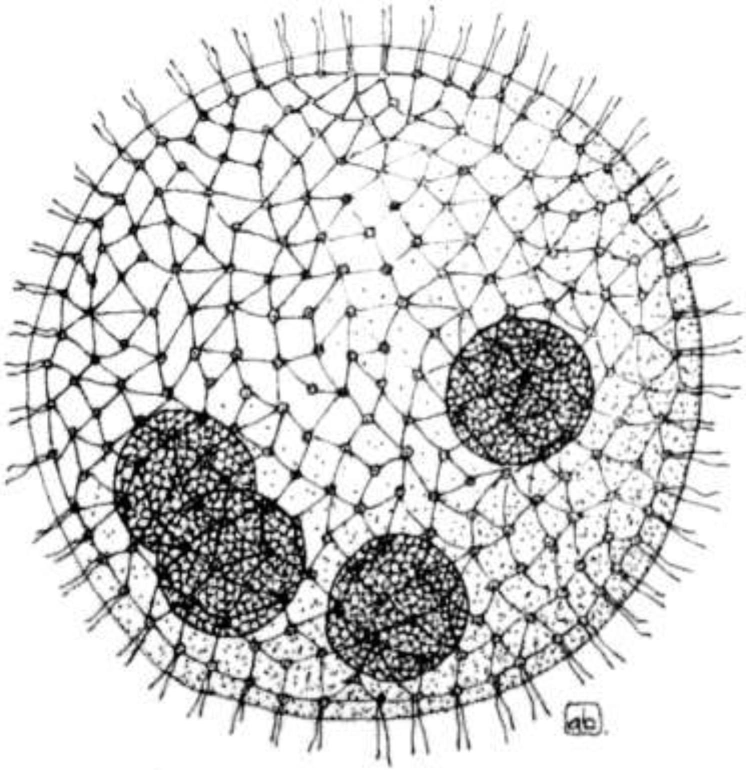


FIGURE 1.5 Motile coenobium of *Volvox aureus.*

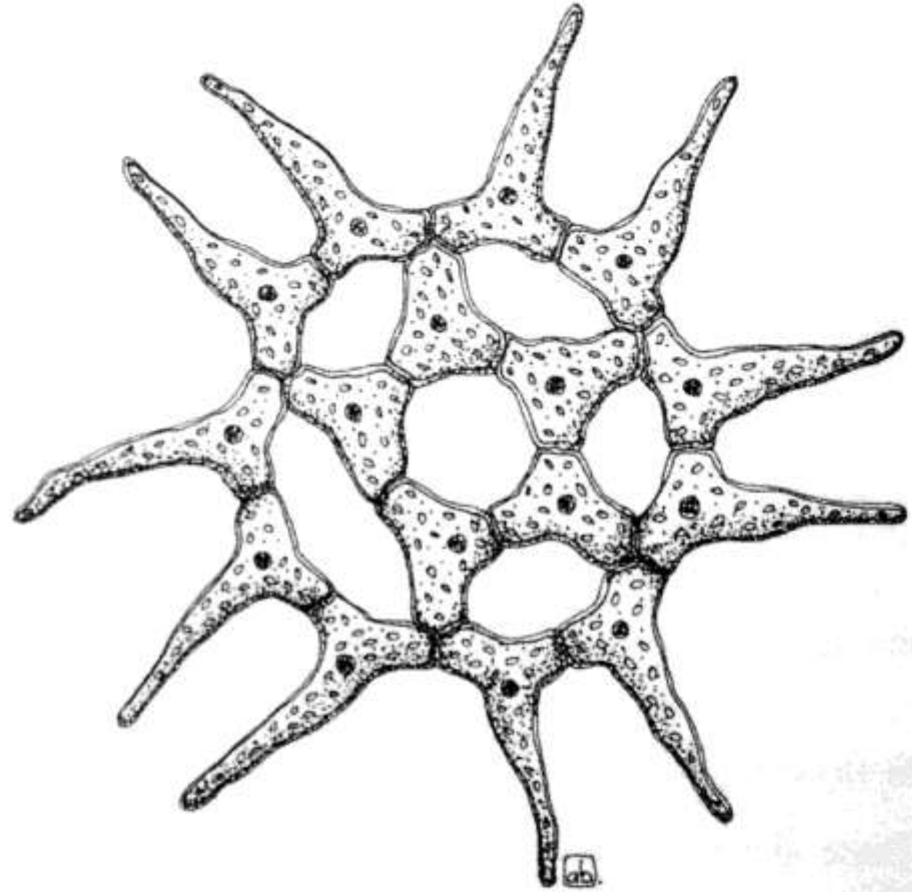


FIGURE 1.6 Non-motile coenobium of *Pediastrum simplex.*

Structure of thallus

Filamentous algae

– result from cell division in plane perpendicular to axis of filament – cell chain

─**simple**

└**branched – true/false**

─**uniseriate** – 1 layer of cells

└**multiseriate** – up to multiple layer

Syphonous algae

– siphonous/coenocytic construction of tubular filaments lacking transverse cell walls

– unicellular but multinucleate (coenocytic)

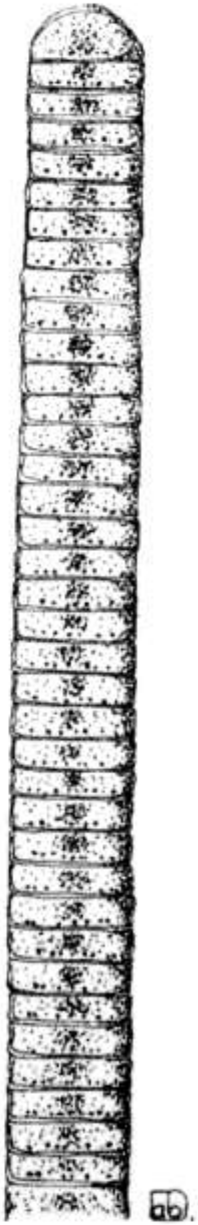


FIGURE 1.7 Simple filament of *Oscillatoria* sp.

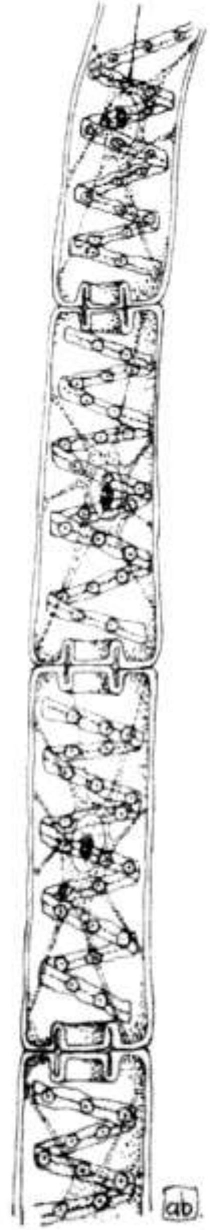


FIGURE 1.8 Simple filament of *Spirogyra* sp.

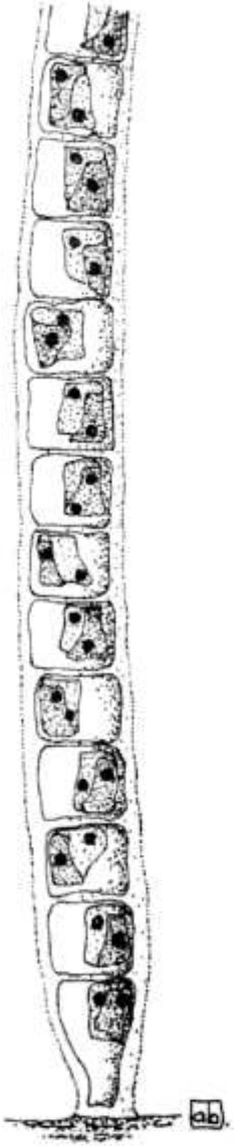


FIGURE 1.9 Simple filament of *Ulothrix variabilis*.

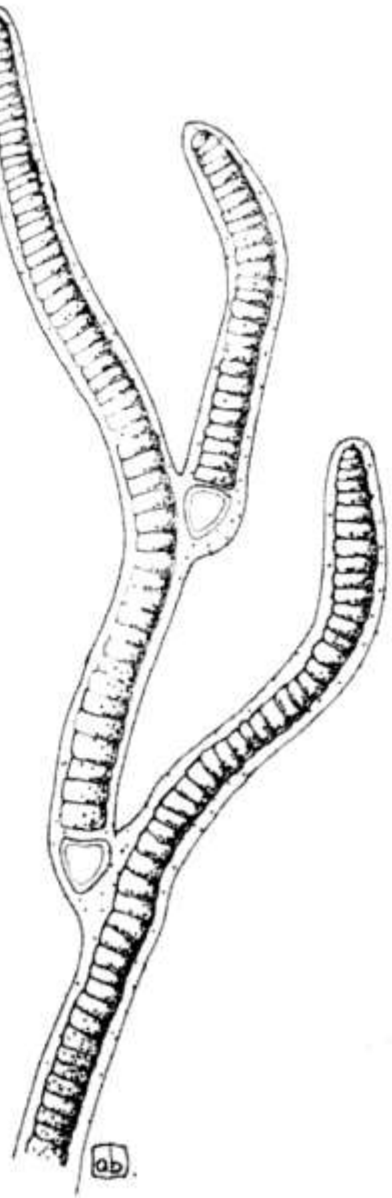


FIGURE 1.10 False branched filament of *Tolypothrix byssoidea.*

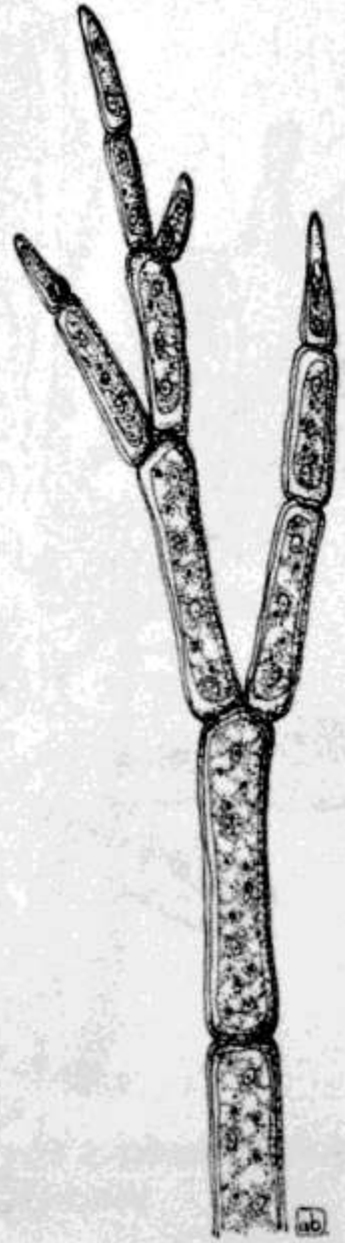


FIGURE 1.11 True branched filament of *Cladophora glomerata.*

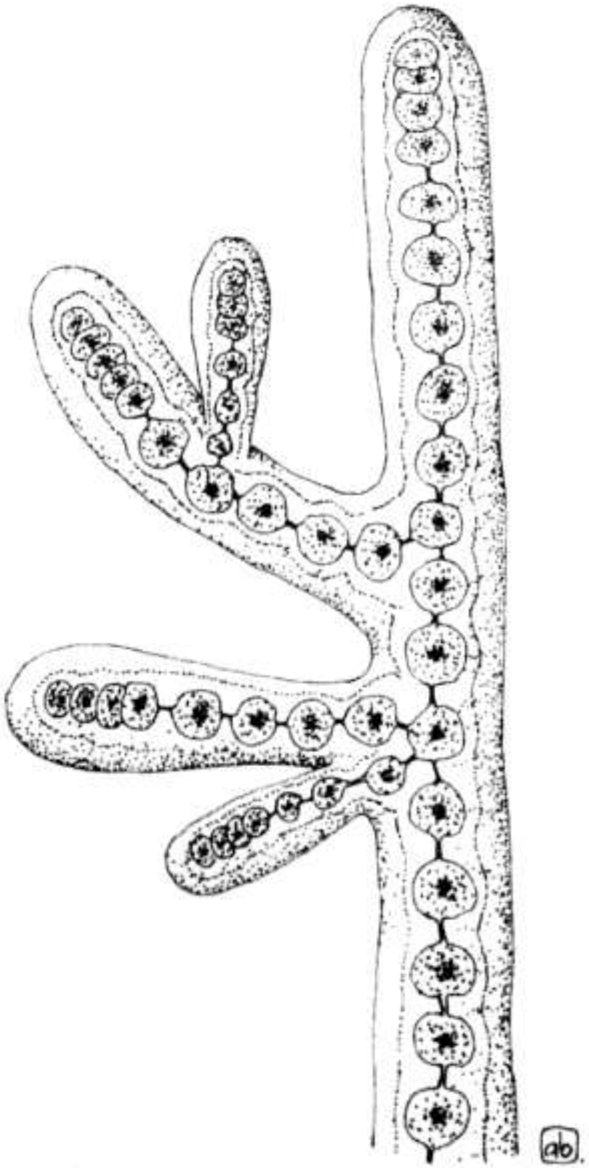


FIGURE 1.12 Uniseriate filament of *Stigonema ocellatum.*

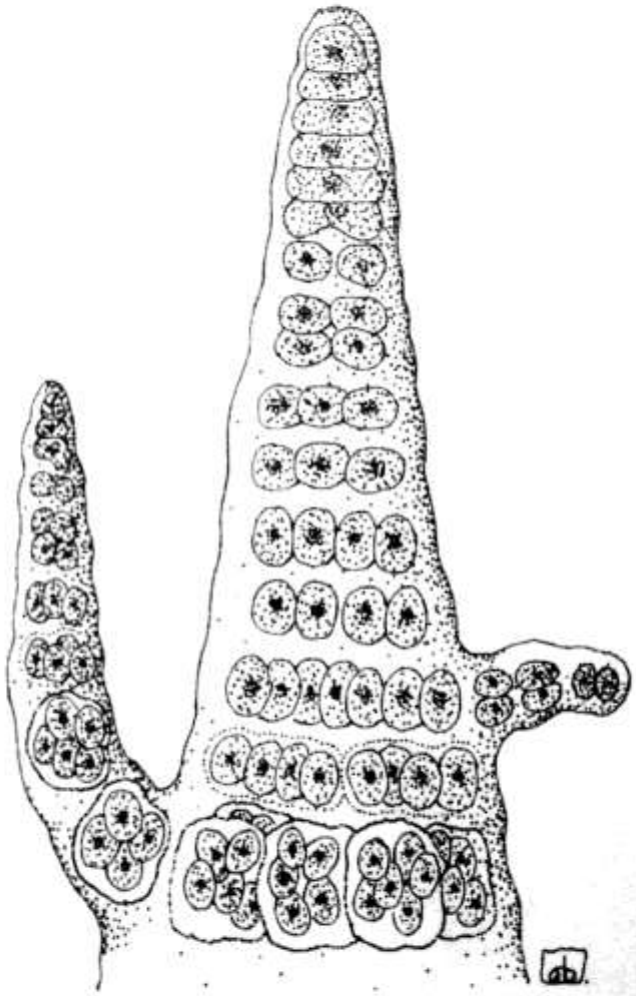


FIGURE 1.13 Multiseriate filament of *Stigonema mamillosum.*

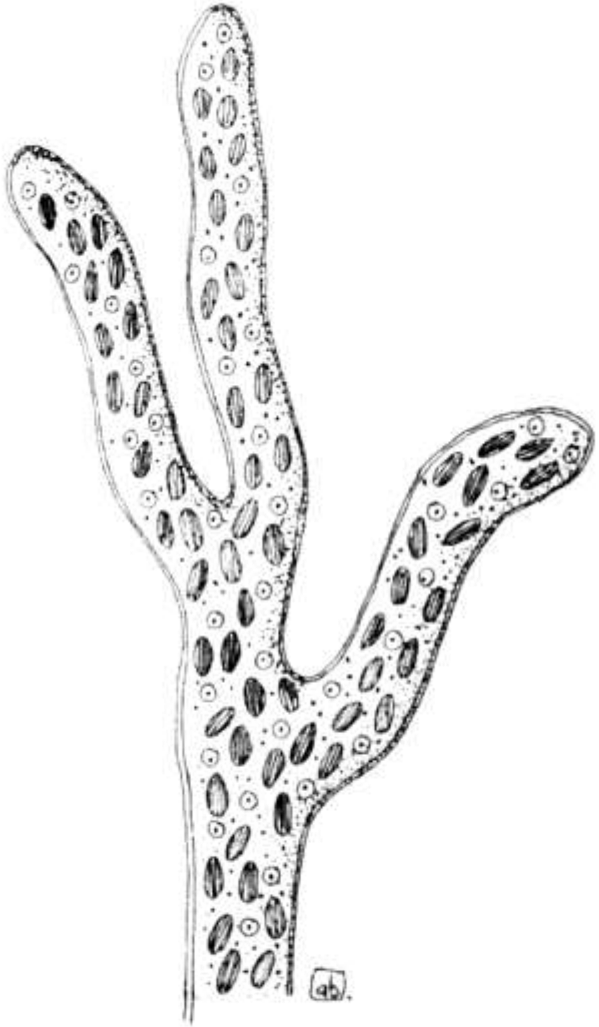


FIGURE 1.14 Siphonous thallus of *Vaucheria sessilis.*

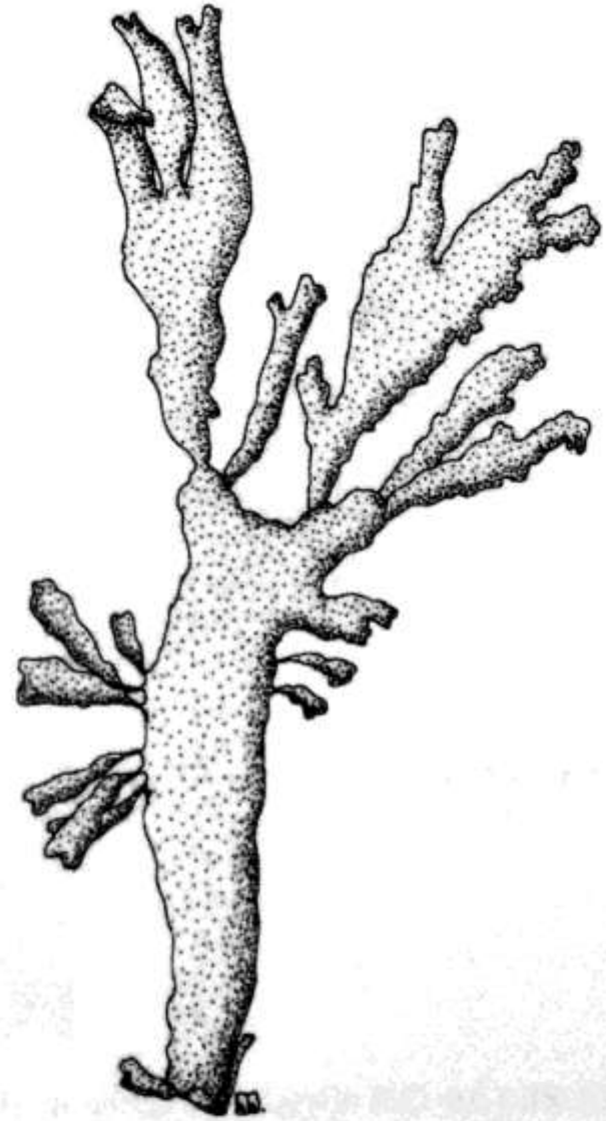


FIGURE 1.15 Pseudoparenchymatous thallus of *Palmaria palmata.*

Structure o thallus

Parenchymatous & pseudoparenchymatous algae

- mostly macroscopic

- **parenchymatous**
  - » originated from division of primary filament (all directions)
  - » lost filamentous structure
- **pseudoparenchymatous**
  - » originated from close aggregation of branched filaments, forming thallus held together with mucilages (red algae)

TABLE 1.3
Thallus Morphology in the Different Algal Divisions

Division	Unicellular and non-motile	Unicellular and motile	Colonial and non-motile	Colonial and motile	Filamentous	Siphonous	Parenche-matous
Cyanophyta	*Synechococcus*	n.d.	*Anacystis*	n.d.	*Calothrix*	n.d.	*Pleurocapsa*
Prochlorophyta	*Prochloron*	n.d.	n.d.	n.d.	*Prochlorothrix*	n.d.	n.d.
Glaucophyta	*Glaucocystis*	*Gloeochaete*	n.d.	n.d.	n.d.	n.d.	n.d.
Rhodophyta	*Porphyridium*	n.d.	*Cyanoderma*	n.d.	*Goniotricum*	n.d.	*Palmaria*
Heterokontophyta	*Navicula*	*Ochromonas*	*Chlorobotrys*	*Synura*	*Ectocarpus*	*Vaucheria*	*Fucus*
Haptophyta	n.d.	*Chrysochro-mulina*	n.d.	*Corym-bellus*	n.d.	n.d.	n.d.
Cryptophyta	n.d.	*Cryptomonas*	n.d.	n.d.	*Bjornbergiella*	n.d.	n.d.
Dynophyta	*Dinococcus*	*Gonyaulax*	*Gloeodinium*	n.d.	*Dinoclonium*	n.d.	n.d.
Euglenophyta	*Ascoglena*	*Euglena*	*Colacium*	n.d.	n.d.	n.d.	n.d.
Chlorarachniophyta	n.d.	*Chlorarachnion*	n.d.	n.d.	n.d.	n.d.	n.d.
Chlorophyta	*Chlorella*	*Dunaliella*	*Pseudo-sphaerocystis*	*Volvox*	*Ulothrix*	*Bryopsis*	*Ulva*

Note: n.d., not detected.

Nutrition

- algae = phototrophs
- most algal divisions – contain colorless heterotrophic spec.
  - **osmotrophy, phagotrophy**
  - **auxotrophy** – cannot synthesize essential components (vitamin B_{12}, fatty acids,..) and have to import them
- algae can use wide spectrum of <u>nutritional strategies</u> combining:
  - phototrophy
  - heterotrophy
  - mixotrophy (relative contribution of photo.&hetero. can vary)
    - » often in extreme environment (limiting light,…)
  - after nutritional strategies:
    - **obligate heterotrophic algae** – primarily heterotrophs, but capable phototrophy in limiting prey concentration *(Gymnodium gracilentum - Dinophyta)*
    - **obligate phototrophic algae** – primarily phototrophs, but capable <u>phagotrophy/osmotrophy</u> when light is limiting *(Dinobryon divergens - Heterocontophyta)*
    - **facultative mixotrophic algae** – can equally well grow as photo-/heterotrophs *(Fragilidinium subglobosum - Dinophyta)*
    - **obligate mixotrophic algae** – primary mode is phototrophy & phago-&/osmotrophy provides essential substances (*e.g*.photoauxotrphs, *Euglena gracilis* - *Euglenophyta*)

Reproduction

- **vegetative** by division of single cell or fragmentation of colony
- **asexual** by production of motile spores
- **sexual** by union of gametes
  - vegetative & asexual
    - » allow stability of adapted genotypes from generation to the next
    - » fast & economical increase of number of individual
    - » lack genetic variability
  - sexual
    - » involves **- plasmogamy** (union of cells)
- karyogamy (union of nuclei) - chromosome/gene association & meiosis >> genetic recombination
    - » allow variation, but is more costly

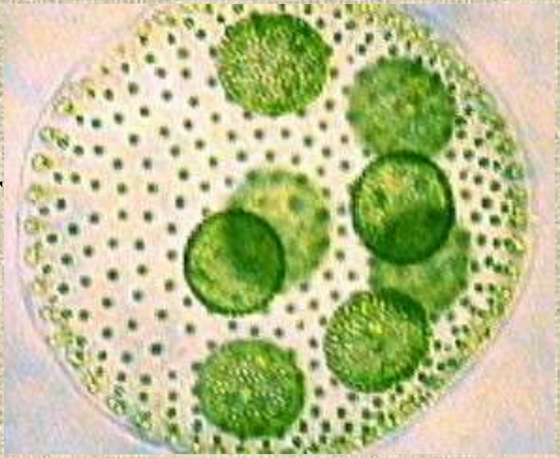
Vegetative & Asexual reproduction

- **Binary fission & Cellular bisection**
  - simplest form
  - parent org. divides into two equal parts of the same hereditary info as parent
  - unicellular a. - <u>longitudinal</u>
- <u>transverse</u>
  - growth of population - lag > exponential > log > stationary (plateau) phase
  - in multicellular a. & colonies - leads to the growth of individual
- **Zoospore, Aplanospore & Autospore**
  - <u>zoospores</u> - flagelate motile spores that may be produced within parental vegetative cell *(Clamydomonas* - *Chlorophyta)*
  - <u>aplanospores</u> - aflagelate spores that begin their development within parent cell wall before being released
- can dvelop into zoospores
  - <u>autospores</u> - aflagelate daughter cells released from ruptured cell wall of parental cell, - replicas of vegetative cells that produce them & lack the capacity to develop into zoospore *(Nannochloropsis* - *Heterocontophyta, Chlorella* - *Chlorophyta)*

spores - may be produced within - ordinary cells
- specialized sporangia

Vegetative & Asexual reproduction

- **Autocolony formation**
  - coenobium/colony - each cell can produce new colony similar to parent.
  - cell division produce multicellular group (not the unicellular individuals) > differs from the parent in cell size not in number *e.g. Volvox (Chlorophyta)*
    - gonidia - series of cells which produce a hollow sphere within the hollow of parental colony (released after its ruptur



- **Fragmentation**
  - ± random process whereby non-coenobic colonies/filaments break into two/several fragments having capacity to develop into new individual

Vegetative & Asexual reproduction

- **Resting stages**
  - under unfavourable conditions (desiccation)
  - thick-walled cells
    - **hypnospores & hypnozygotes**
      - thick-walled, produced *ex novo* from cells previously separated from parent cells
        - » **hypnospores** - *Ulothrix spp., Chlorococcum (Chlorophyceae)*
        - » **hypnozygotes** - *Spyrogyra spp. (Chlorophyceae), Dinophyta*
      - enables algae to survive temporary drying out of small water bodies & allow transport to another (*e.g.* via birds)
    - **statospores**
      - endogenous cysts formed within vegetative cells by members of *Chrysophyceae e.g. Ochromonas spp.*
        - » cyst walls consist of silica >> preserved as <u>fossils</u>
      - spherical, ellipsoidal, often ornamented with spines or other projections
      - wall - with pores sealed by unsilicified bung
      - within cysts lie nucleus, chloroplasts, reserve material
      - after dormancy - germination - form one/several flagellate cells
    - **akinetes** occurrence in blue-green algae
      - enlarged vegetative cells that develop thickened wall in response to limiting env. nutrients or light *(e.g. Anabaena cylindrica - Cyanophyta)*
      - extremely resistant to drying & freezing
      - long-term anaerobic storage of genetic material, remain viable in sediments for many years in hard conditions
      - in suitable conditions > germination into new vegetative cells

Sexual reproduction

Gametes

- morphologically identical/different with/from vegetative cells (a. group speciphic sign)
- haploid DNA content
- possible different gamete types

- **isogamy** - both gametes types motile & indistinguishable
- **heterogamy** - gametes differ in size
  - » **anisogamy** - both gametes are motile, 1. small - sperm
2. large - egg
  - » **oogamy** - 1. motile, small - sperm
2. non-motile, very large - egg

Algae exhibit 3 different life cycles with variation within different groups

- main difference - where meiosis occur & type of cells it produces & whether there is more than one free-living stages

Sexual reproduction

Haplontic or zygotic life cycle

- single predominant haploid vegetative phase, with meiosis after germination of zygote
  - » *Chlamydomonas (Chlorophyta)*

Diplontic or gametic life cycle

- single predominant diploid vegetative phase
- meiosis gives rise to haploid gametes
  - » *Fucus (Heterocontophyta), Diatoms*

Haplontic or zygotic life cycle

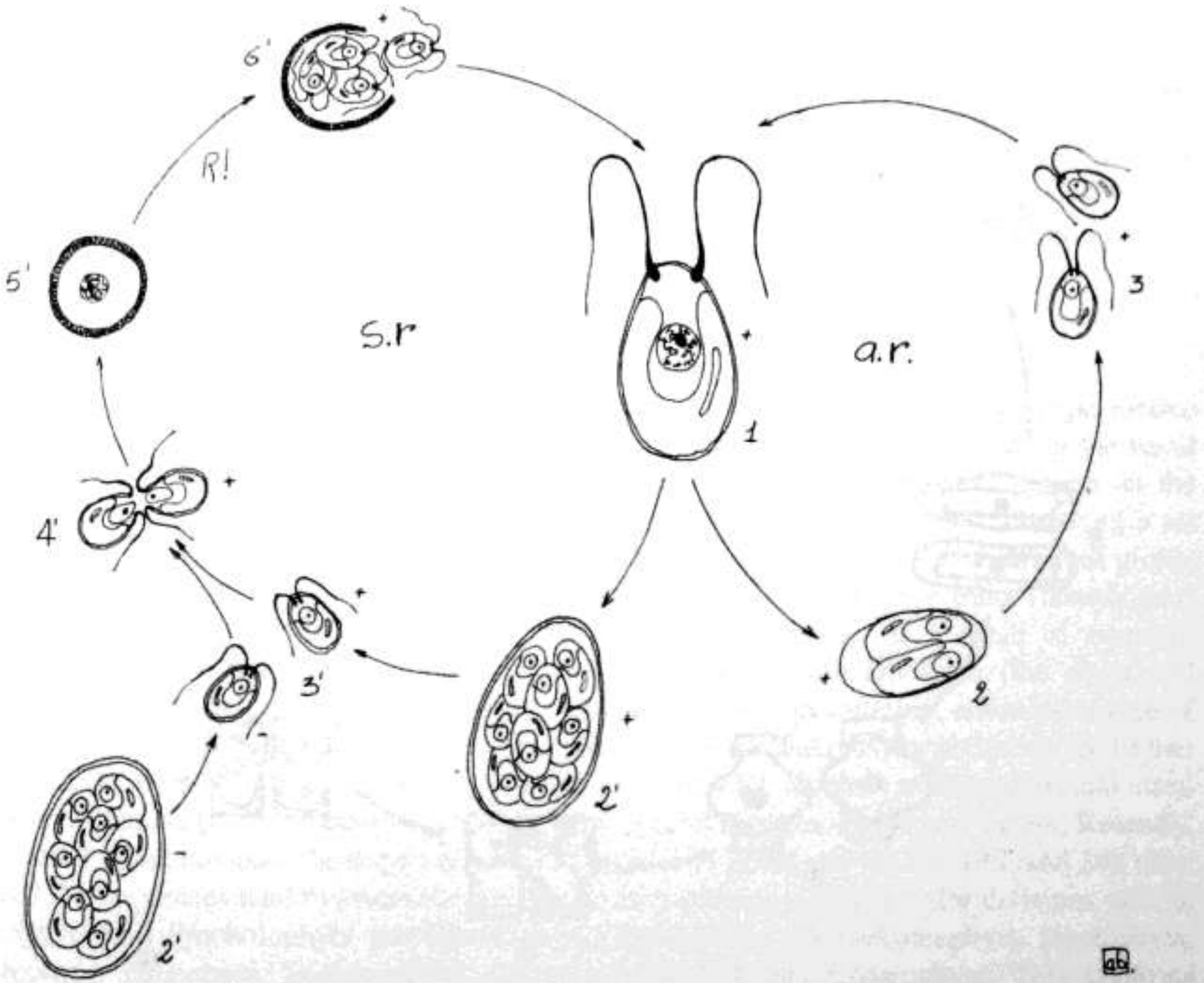


FIGURE 1.19 Life cycle of *Chlamydomonas* sp.: 1, mature cell; 2, cell producing zoospores; 2′, cell producing gametes (strain+ and strain−); 3, zoospores; 3′, gametes; 4′, fertilization; 5′, zygote; 6′, release of daughter cells. R!, meiosis; a.r., asexual reproduction; s.r., sexual reproduction.

Diplontic or gametic life cycle

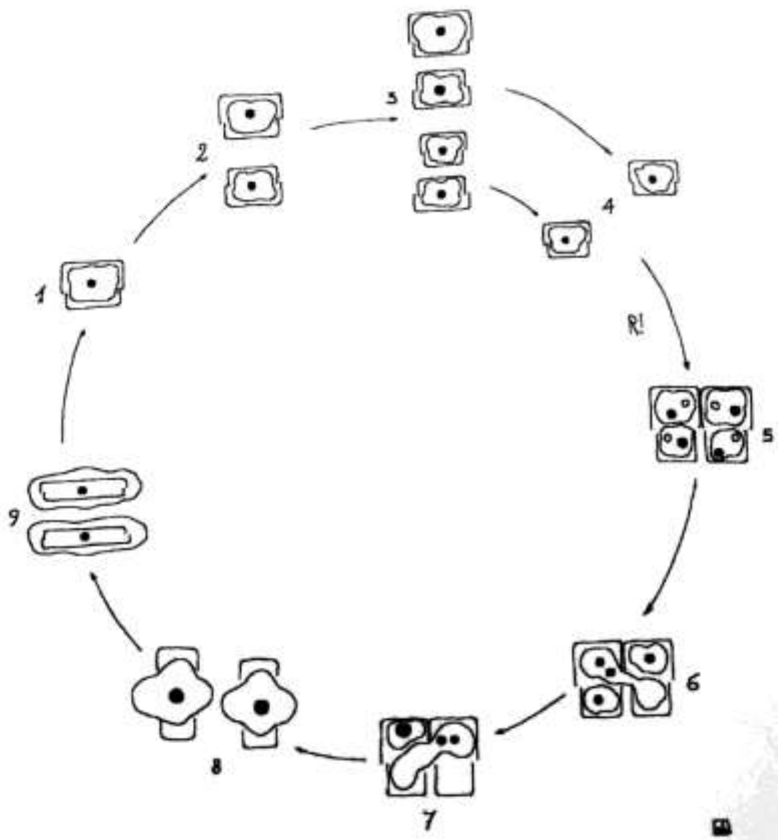


FIGURE 1.20 Life cycle of a diatom: 1, vegetative cell; 2, 3, vegetative cell division; 4, minimum cell size; 5, gametogenesis; 6, 7, fertilization; 8, auxospores; 9, initial cells. R!, meiosis.

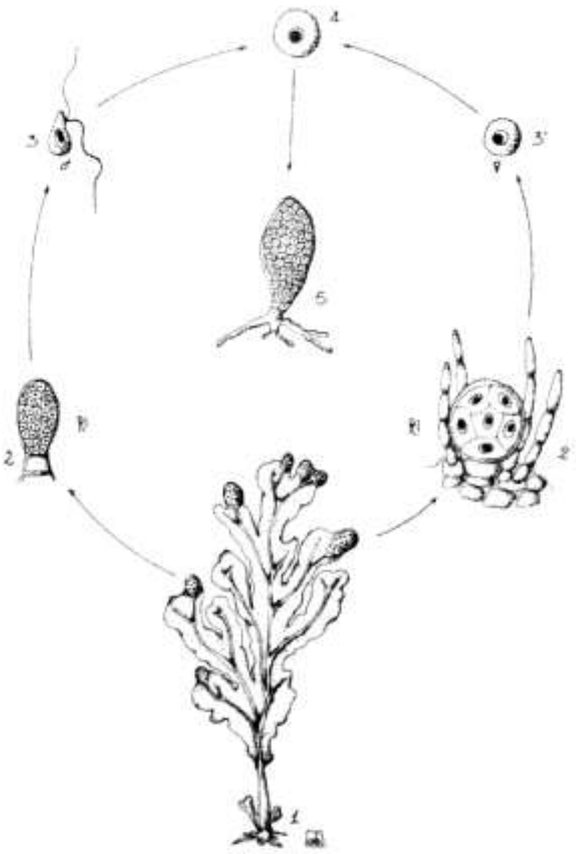


FIGURE 1.21 Life cycle of *Fucus* sp.: 1, sporophyte; 2, anteridium; 2′, oogonium; 3, sperm; 3′, egg; 4, zygote; 5, young sporophyte. R!, meiosis.

Sexual reproduction

Diplohaplontic or sporic life cycle

- present alternations of generation between two different phases consisting of haploide gametophyte & diploid sporophyte
    - **gametophyte** - produce gamete by mitosis
    - **sporophyte** - produce spore by meiosis
- alternation of generations can be
    - **isomorphic** - both phases morphologicaly identical
        - » *Ulva (Chlorophyta)*
    - **heteromorphic** - with predominance of
        - sporophyte - *Laminaria (Heterocontophyta)*
        - gametophyte - *Porhyra (Rodophyta)*

Diplohaplontic or sporic life cycle

-isomorphic alternation of generations

FIGURE 1.22 Life cycle of *Ulva* sp.: 1, sporophyte; 2, male zoospore; 2′, female zoospore; 3, young male gametophyte; 3′, young female gametophyte; 4, male gametophyte; 4′, female gametophyte; 5, male gamete; 5′, female gamete; 6–8, syngamy; 9, young sporophyte. R!, meiosis.

Diplohaplontic or sporic life cycle

-heteromorphic alternation of generations

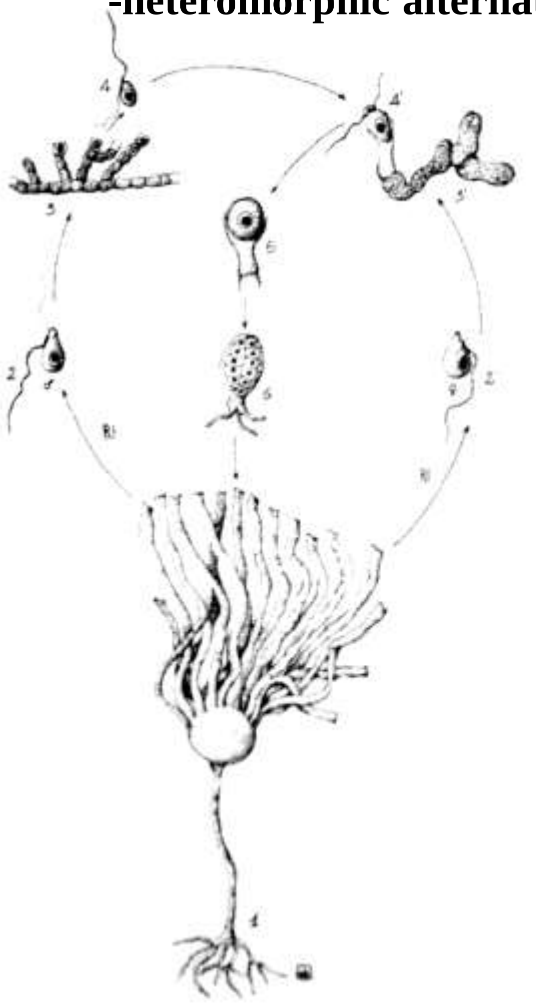


FIGURE 1.23 Life cycle of *Laminaria* sp.: 1, sporophyte; 2, male zoospore; 2′, female zoospore; 3, male gametophyte; 3′, female gametophyte; 4, sperm; 4′, egg and fertilization; 5, zygote; 6, young sporophyte. R!, meiosis.

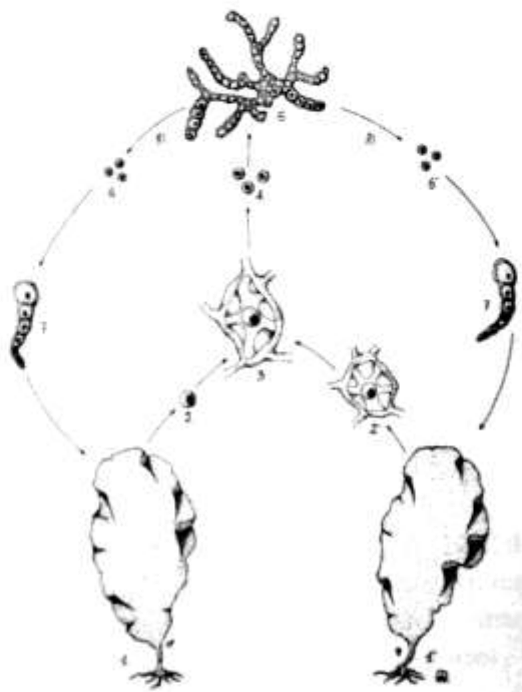


FIGURE 1.24 Life cycle of *Porphyra* sp.: 1, male gametophyte; 1′, female gametophyte; 2, sperm; 2′, egg; 3, fertilization and zygote; 4, spores; 5, sporophyte; 6, male spore; 6′, female spores; 7, young male gametophyte; young female gametophyte. R!, meiosis.