Discipline Courses-I
Semester-I
Paper: Phycology and Microbiology
Unit-XI
Lesson: Rhodophyceae
Lesson Developer: Charu Khosla Gupta
College/Department: Acharya Narendra Dev College, University of Delhi

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Chapter: Rhodophyceae

Introduction

The Rhodophyceae or the Red algae is probably the oldest groups of Eukaryotic Algae encompassing about 4000 species of mostly multicellular and predominantly marine algae. It is the only class in the division Rhodophyta.

The members Rhodophyceae along with some members of Chlorophyceae and Phaeophyceae form a group of macro algae commonly called as seaweeds. They owe their red color to the photosynthetic pigment phycoerythrin. Despite their name, not all Rhodophyceae are red. These algae may also be purple, brown or black because of presence of the additional pigments. The pigments present are chlorophyll a, chlorophyll d, carotenes, phycoerythrins and phycocyanins.

Main characteristic features of Rhodophyceae:

- Most of the red algae are marine
- Motile cells are not found in this group. Even the gametes and the spores lack flagella.
- Excess of the photosynthates are stored as **floridean starch** in the cytoplasm as small granules. Floridean starch is a branched polymer of glucose very similar to glycogen.
- The unique photosynthetic pigments include- **chlorophyll–d**, **phycobilins: r-phycoerythrin** and **r-phycocyanin** and the xanthophyll-**taraxanthin** besides the general chlorophyll-a and the α and β-carotene, lutein, zeaxanthin, neoxanthin.
- The cell wall contains **polysulphate esters of carbohydrates** in addition to cellulose and pectin.
- Adjacent cells are connected to each other by specialized pits. The pit connections contain a specialized lens shaped plug locked in a septal aperture.
- Reproduction is specialized with male gamete- **spermatium** being non motile. It is carried passively by the water currents and is lodged in the **trichogyne** of the female sex organ –**carpogonium**. The post fertilization changes are also unique in this group.

Fritsch 1935 divided the class into two orders-

- Bangioideae – in which there is intercalary growth of the thallus and
  - there is direct division of the zygote into carpospores
- Florideae - in which the growth of the thallus is terminal and

- the carpospores are formed indirectly from a zygote.

Occurrence

Among the seaweeds the number of red algae is much more than all other seaweeds belonging to all other groups of algae. Although marine algae occur at all latitudes they are predominantly seen in temperate and tropical regions. Very few species occur in polar and sub polar regions (Lee, 2008). Larger species of red algae occur in cool temperate areas whereas mostly small and filamentous forms are found in tropical seas. They can survive at great depths of up to 200m, an ability dependent on the presence of accessory pigments.

Fresh water Rhodophycean algae (about 200 species) do not reach as great a size as the seaweeds and are generally found in running waters of small streams (Sheath and Hambrook, 1988).

The Rhodophycean organisms range from autotrophic, independent complete plants to completely heterotrophic parasites. This includes non- obligate epiphytes (*Achrochaetium-Rhodocorton* complex), obligate epiphytes *(Polysiphonia lanosa* on *Ascophyllum*), semi parasites which have some photosynthetic pigments and parasites with no photosynthetic machinery. Parasitic red algae are divided into adelphoparasites (closely related to the host hence easier to establish pit connections) and alloparasites (not closely related to their hosts).

Figure: Red alga *Polysiphonia lanosa*, an obligate epiphyte on *Ascophyllum nodosum.*

Source:http://upload.wikimedia.org/wikipedia/commons/9/93/Ascophyllum_nodosum_with_Polysiphonia_lanosa.jpg

Range of thallus

The red algae usually have multicellular and macroscopic thalli with only a few unicellular species like *Porphyridium, Rhodospora*. The thalli can be filamentous, membranous, foliaceous or even parenchymatous like *Bangia*. The filamentous thalli are composed of varying number of parallel strands. Some forms may have an outer covering of corticating filaments. A thallus which possesses a single axial filament having branched laterals with or without cortication is called a uniaxial filament (*Achrochaetium*). Those thalli which possess a tuft of axial filaments with many laterals radiating out to the margins are called multiaxial filaments. Some of the red algae are stony due to heavy impregnation of lime and hence called the coral reefs (*Corallina, Lithothamnion*). In general branching is monopodial and growth apical.

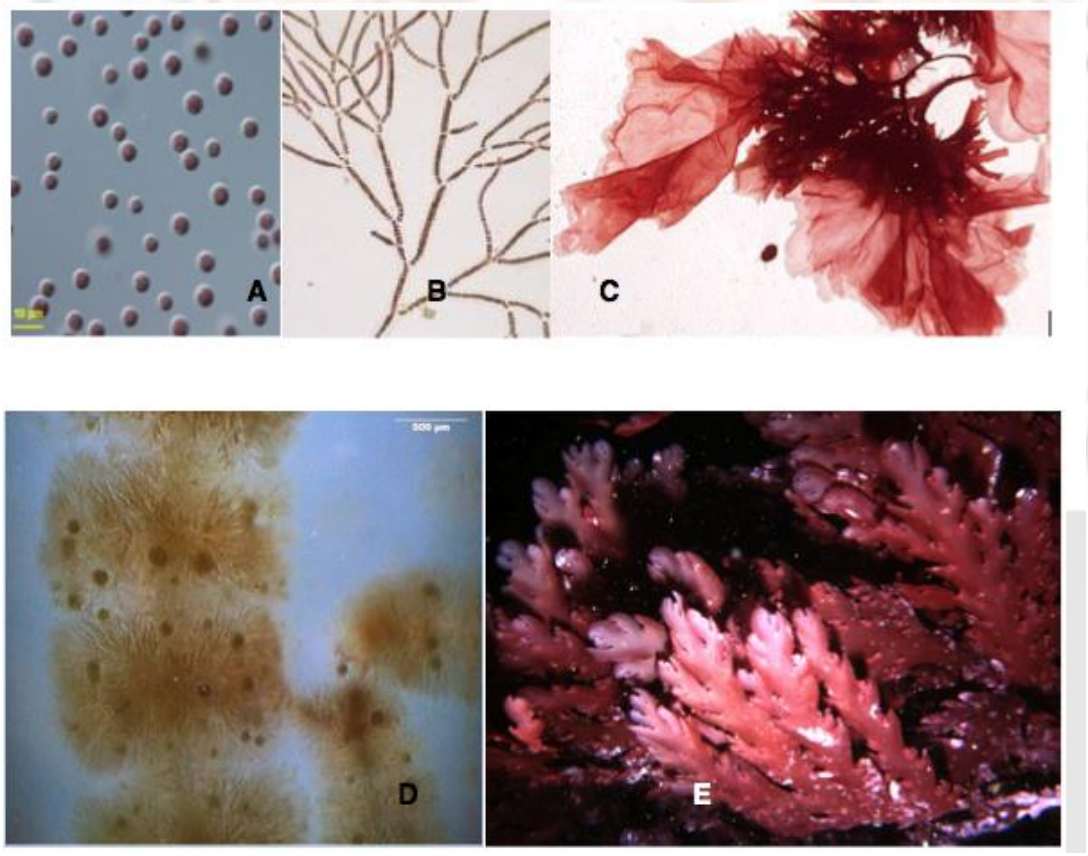
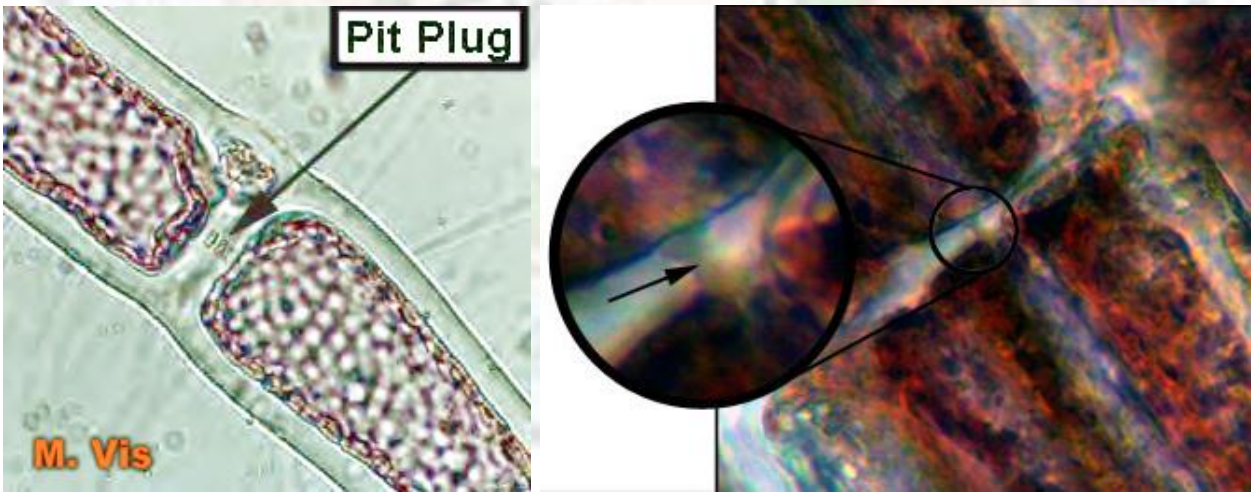


Figure: Range of thallus in Rhodophyceae**-A.** Unicellular-*Pophyridium*; B.filamentous *Goniotrichum*; C. parenchymatous *Porphyra*; D. pseudoparenchymatous (with a number of filaments apprised together to form a pseudo (false) parechymatous structure in *Batrachospermum* and;E. *Polycamium* that is one of the most beautiful marine algae

Source:http://content61.eol.org/content/2008/12/10/20/10847_580_360.jpg, http://media.eol.org/content/2010/12/04/04/75283_260_190.jpg, http://biomesfourth09.wikispaces.com/file/view/porphyra.gif/102198671/porphyra.gif, http://upload.wikimedia.org/wikipedia/commons/b/b6/Batrachospermum_moniliforme.jpg,http://upload.wikimedia.org/wikipedia/commons/a/ae/Plocamium_corallorhiza.jpg

Pit connections

Pit connections are unique to red algae. These are the connections between two adjacent cells that are filled with protein. These consist of plugs and caps. Pit connections are the sites of structural strength in the thallus. In some algae, the plugs become dislodged in the reproductive cells hence allowing the passage of metabolites to the developing reproductive cells. The pit connections between the axial cells and the pericentral cells are called as the primary pit connections. Those between the adjacent pericentral cells are the secondary pit connections.



A **B**

Figure: A. Picture of a protein pit plug breaking continuity between cells ;B. Enlarged view of a secondary pit connection

Source: http://www.biologie.uni-hamburg.de/b-online/library/webb/BOT311/Rhodophyta/PitPlugLMVisHue.jpg, http://www.mbari.org/staff/conn/botany/reds/sarah/images/pitplugcloser.jpg

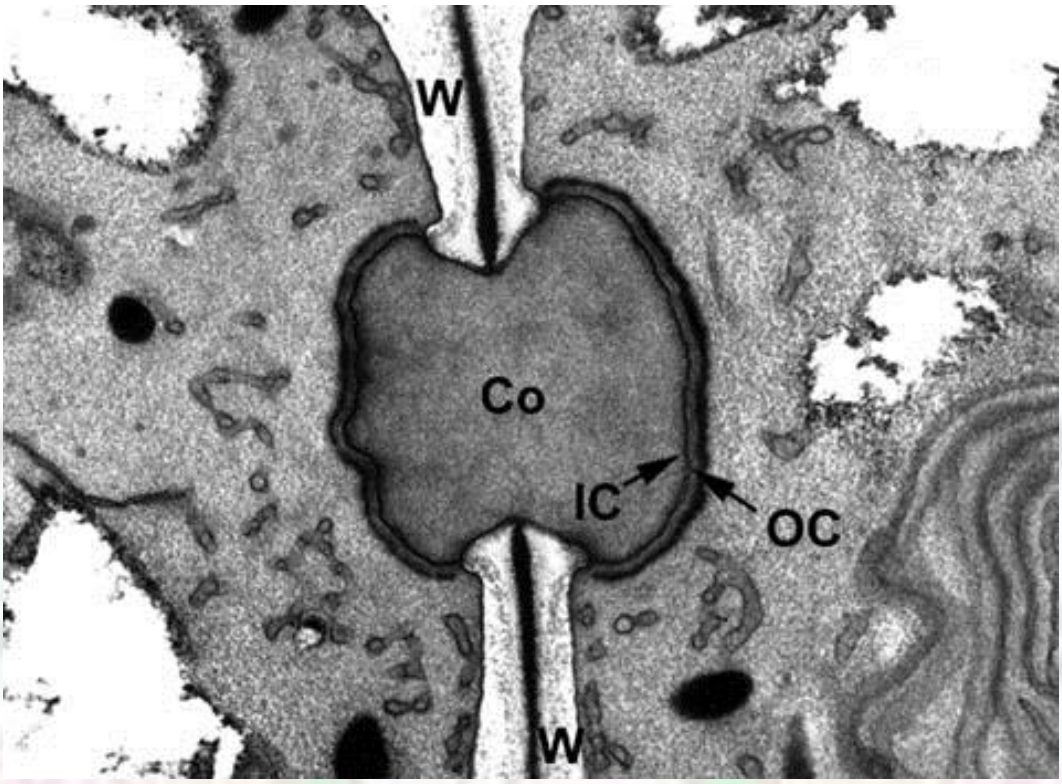


Figure: Electron micrograph showing the details of a pore plug. The wall(W) has a central core plug (Co) flanked on either side by the inner cap (IC) and outer cap (OC).

Source: http://tolweb.org/tree/ToLimages/florchar1.jpg

Formation of pit connections - Soon after nuclear division, the cross wall moves inwards from the sides. When the cross wall is complete, there remains a hole in the center through which the protoplasm of the two cells is in contact. A number of parallel vesicles traverse the hole with electron dense material condensing around the apertures. Eventually, the vesicles disappear and the electron dense material fills the hole. A membrane is formed around this electron dense material, producing a plug in the hole. In the end, a plug cap appears on each side of the plug. This is formed by a flattened vesicle only.

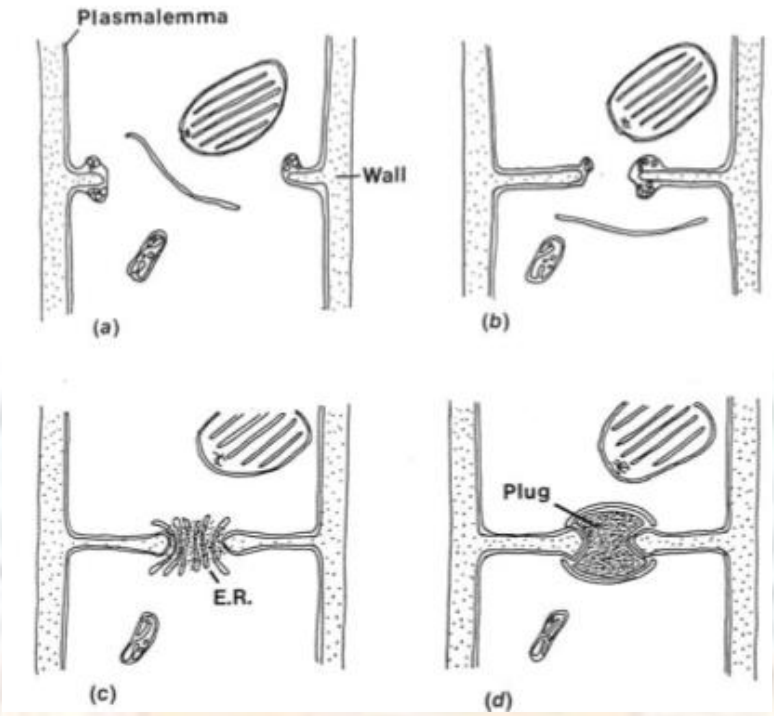


Figure: Formation of pit connections

Source: Author

Open communications do not occur between cells of red algae. Spermatia, tetraspores and carpospores are liberated from apertures formed by displacement of pit connections.

Calcification

Some members of Corallinaceae (coralline red algae) deposit calcium carbonate extracellularly in their cell walls. Due to this deposition the plants become rock like in appearance and were mistaken for corals till 1837 (Lee,2008).

Figure: The coralline algae: *Liagora, Galaxura,Amphiroa anceps,*

Source:http://www.marinelifephotography.com/marine/seaweeds/liagora-albicans.jpg

http://www.marinelifephotography.com/marine/seaweeds/Galaxaura-obtusata.JPG

http://www.reefwatchvic.asn.au/images/biology/190.jpg

Anhydrous calcium carbonate occurs in two crystalline forms: calcite with rhomboidal crystals (Corallinaceae; Gigartinales) and aragonite with orthorhombic crystals(Nemaliales). The two forms differ markedly in specific gravity, hardness and solubility.

Iridescence

Most thalli of Rhodophyceae show a marked blue or green iridescence under reflected light. This is a play of colours caused by refraction and interference of light waves at the surface of water. This is only a physical interference and not related to any light-producing phenomenon like phosphorescence or bioluminescence.

Figure: Iridescent red alga *Fauchea laciniata.*

Source: http://upload.wikimedia.org/wikipedia/commons/a/a9/Fauchea_laciniata.jpg

Cell Structure

Cells are non motile and eukaryotic with chloroplast having one thylakoid per band. Chloroplast Endoplasmic Reticulum is absent and the Floridean starch is found in the cytoplasm outside the chloroplast. Pit connections are seen in filamentous forms (Scott et al; 1980).

Cell Wall

The cell wall in red algae is called as extracellular matrix (ECM) as it is less rigid in comparison to walls in other groups. The microfibrillar framework in most Rhodophycean cell walls is provided by cellulose, although in *Porphyra* and *Bangia*, a xylan performs this function. These microfibrils are filled with an amorphous matrix of sulfated galactan polymers and mucilage. Mucilages make up to 70% of dry weight of the cell wall (Lee, 2008). Unicellular red algae have an amorphous matrix of sulfated polysaccharides without cellulose.

The red algal cell wall contains various types of highly hydrophilic, sulfated polygalactans which are polymers of β-(1➔4) Galactose and α-(1➔3) linked anhydrogalactose. These are components of the economically important products from red algae - **agars** and **carageenans** both being galactans. In the presence of cations such as Ca^{+2} or K^{+} these sulfated galactans aggregate into three-dimensional networks that have colloidal properties.

The mucilages are polymers of D-xylose and D-glucose, D-glucuronic acid and galactose. Sulfated mannans are also found in certain genera.

Chloroplast and storage products

Chloroplasts usually originate from small colourless proplastids and are surrounded by two membranes of the chloroplast envelope. Chloroplasts are usually stellate with a central pyrenoid in morphologically simple Rhodophyceae, whereas in others it is discoid.

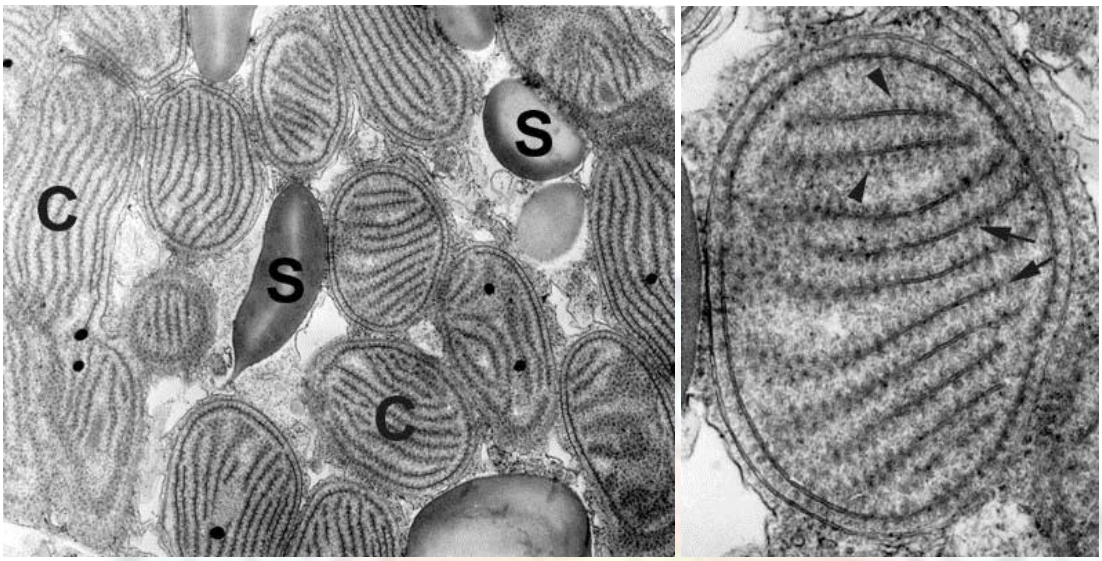


Figure: A. *Griffithsia pacifica* electron micrograph showing numerous chloroplasts (C) and starch grains (S). B. magnified view of the unstacked thylakoids and the phycobilisomes(arrow) containing the water soluble pigments-phycobilins

Source:http://tolweb.org/tree/ToLimages/redchar1.jpg,http://tolweb.org/tree/ToLimages/redchar2.jpg

Phycobiliproteins are present in phycobilisomes which occur on the surface of the thylakoids. If both phycoerythrin and phycocyanin are present then the phycobilisomes assume a spherical shape and if only phycocyanin is present then phycobilisomes are discoid. All light absorbed by the phycobiliproteins is primarily transferred to chlorophyll a which is involved in Photosystem II, phycobilisome with all its phycobiliproteins serves as an antenna funneling all light towards the reaction centre of Photosystem II. Phycocyanin and phycoerythrin are also present in Cyanobacteria or the blue green algae. Actual quantities of pigments vary with the depth of the water body. Those members which do not have much phycoerythrin appear green or blue (*Batrachospermum*). Phycoerythrin allows red algae to live and photosynthesize at great depths below the surface of the oceans. Phycoerythrin has the ability to absorb blue light, which penetrates water at greater depths than light of longer wavelength generally used for photosynthesis.

Floridoside is a major photosynthate in Orders Bangiales, Nemaliales, Rhodymeniales. The concentration of floridoside increases with the increase in salinity of the medium. Floridean starch is a long term storage product occurring in the form of grains in the cytoplasm of the cell outside the chloroplast. It stains red-violet with iodine. It differs from chlorophycean

starch in being devoid of amylase. In primitive Rhodophyceae the starch grains are clustered as a sheath around the pyrenoid whereas in advanced forms the starch grains are found scattered in the cytoplasm.

Cell Division

The red algae have several unique features with regards to mitosis:

- The nuclear membrane remains intact throughout mitosis
- Centrioles are absent
- Instead a distinctive organelle called as polar ring or nuclear associated organelle (NAO) occurs at the spindle poles that are associated with the microtubules.

Reproduction

Reproduction occurs by both asexual and sexual methods. There is absence of any flagellated structures. Asexual reproduction takes place by means of spores and fragmentation of the thalli. Spores are non motile and are given different names depending on the nature of cells from which they are produced and their number within each sporangium namely: monospores-formed singly in monosporangia, neutral spores-formed by direct transformation of vegetative cells into spores, carpospores-formed by division of zygote and bispores, tetraspores and polyspores formed within diploid tetrasporangium in multiples of two, four and multiples of four.

The sexual life histories of red algae have two (Diphasic) or three multicellular phases (Triphasic).

Triphasic Life Cycle

Most of the red algae have three distinct phases in their life cycle- the **gametophyte, carposporophyte** and the **tetrasporophyte**.

- Gametophyte is a free-living haploid plant which is concerned with sexual reproduction. It produces the gametes.
- Carposporophyte is a diploid plant which develops from the zygote after sexual fusion is accomplished. It is parasitic on the female gametophyte and hence remains attached to it. Carposporophyte is concerned with the production of diploid spores called the carpospores. Carpospores germinate to give rise to tetrasporophyte.
- Tetrasporophyte is an independent plant like the gametophyte . It is the site of meiosis and is concerned with the production of haploid spores called the

tetraspores. Tetraspores further germinate to give rise to gametophyte of the next generation.

Diphasic Life Cycle

In simple red algae like *Batrachospermum*, the carpospores are haploid and on germination produce sexual plants. There is no asexual plant except the diploid zygote which soon undergoes meiosis. Thus there are three haploid generations

- the parent gametophyte concerned with the production of gametes. It is independent;

- carposporophyte concerned with production of carpospores which are haploid. It is parasitic on the female gametophyte;

- carpospores which germinate to form the **charantia** stage which gives rise to the gametophytes.

The life cycle of *Batrachospermum* thus involves alternation of successive haploid generations with the diploid zygote. Cytologically it is haplobiontic with only one kind of individuals. On the other hand, life cycle of *Polysiphonia* is typically triphasic with two diploid and one haploid generation. Cytologically, such life cycles are diplobiontic in which there is a regular alternation of one gametophyte phase with two sporophyte phases.

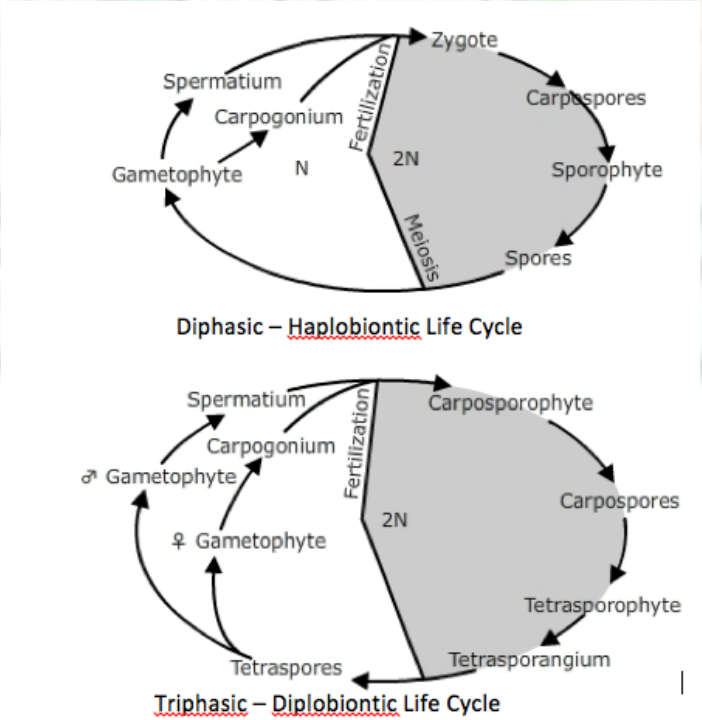


Figure: The two types of life cycle found in Rhodophyceae

Source: Author

Carpogonium

It is the female sex organ and consists of a dilated basal portion and a very narrow elongated tip, the trichogyne.

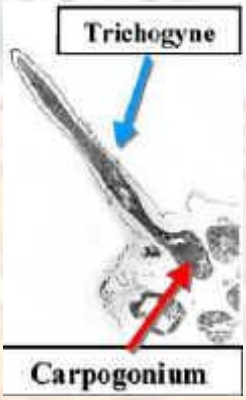


Figure: Female reproductive structure- Carpogonium**.** The blue arrow points to the elongated trichogyne and the red to the dilated base.

Source:http://www.biologie.uni-hamburg.de/b-online/library/webb/BOT311/Rhodophyta/Trichogyne300Lab_small.jpg (With Permission)

The trichogyne is gelatinous and and is instrumental in receiving the male cells. A carpogonium usually possesses two nuclei; one in the trichogyne and the other in the basal part. The trichogyne nucleus degenerates soon after the carpogonium attains maturity whereas the nucleus in the basal part functions as the female gamete nucleus.

Carpogonium arises in the terminal portion of a 3-4 celled carpogonial branch and the cell which gives rise to carpogonium is the supporting cell. Both the carpogonium and the carpogonial branch are generally colourless.

Spermatium

It is the male sex organ and is generally spherical or oblong in shape. One spermatium is produced per spermatangium. A young spermatium has nucleus towards apex and vacuoles towards the basal region which fuse at maturity. These vacuoles contain mucoplysaccharides and make up for half the volume of the spermatangium. Spermatia are released by the gelatinization of the spermatangial wall near the apex. The fibrous material

(mucopolysaccharides) swells and pushes the spermatium out of the spermatangium. As the fibrous material is sticky some of it may get stuck to the spermatium and later help it in attaching to the trichogyne. A mature spermatium is a uninucleate structure with no cell wall. It is generally enclosed in mucilage and may or may not contain chloroplasts.

Fertilisation

Water currents carry the spermatia to the trichogyne of the carpogonium. The walls of the male and female gametes dissolve at their point of attachment thus facilitating the movement of the male nucleus to the carpogonium. Fusion of the male and the female gametes takes place in the basal portion of the carpogonium. The fertilized carpogonium does not form a diploid zygote as seen in other groups of algae but instead puts out another long filament that carries the diploid nucleus out of the carpogonium and deposits it into a totally different cell called as the auxillary cell which is in close proximity of the carpogonium. Auxillary cells are of two types: nutritive and generative. Nutritive cells provide nutrients for developing carposporophyte. And the generative cells give rise to gonimoblast filaments. It is the diploid tissue of fertilized carpogonium which forms the gonimoblast filaments. As already discussed these gonimoblast filaments bear terminal carposporangia which form the carpospores. Carposporangia enlarge because of development of chloroplasts and vesicles containing wall precursors. Breaking of pit connections between the carposporangium and gonimoblast filaments lead to release of carpospores.

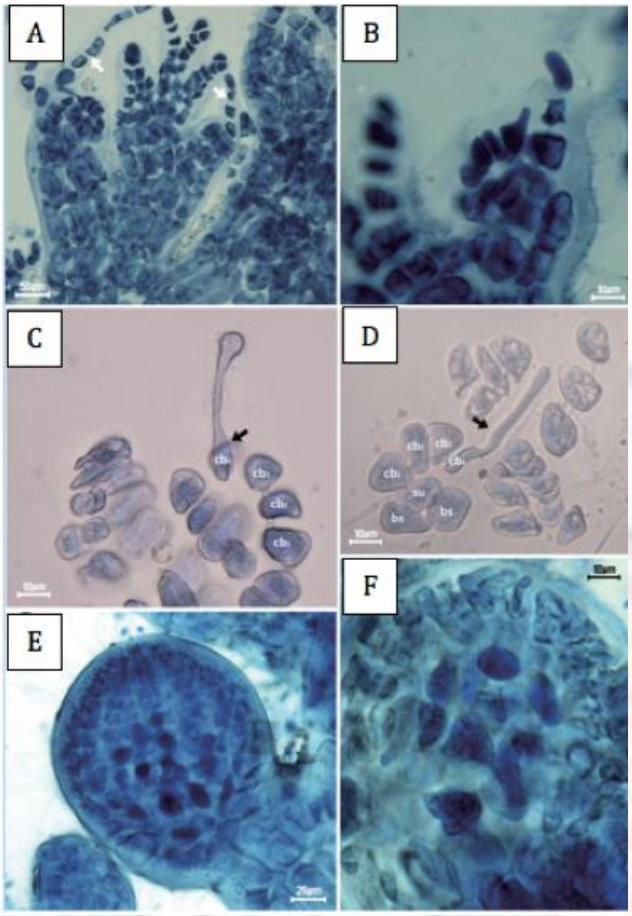


Figure: Red alga *Symphocolax koreana* - A. Fertile branch with trichoblast; B-D.Carpogonium. cb- carpogonial branch cells with numbers and bs- basal sterile cells. Note the presence of elongated trichogyne (arrow). E-F. Cystocarp containing the gonimoblast.

Source:http://central.oak.go.kr/search/detailarticle.jsp?article_seq=10658&tabname=abst&resource_seq=null&keywords=null#Fig.%203. (CC-BY)

Onset of mitosis in carpospores produces a mass of new cells. This mass of cells gives rise to a new generation called as the carposporophyte and it produces carpospores by mitosis.

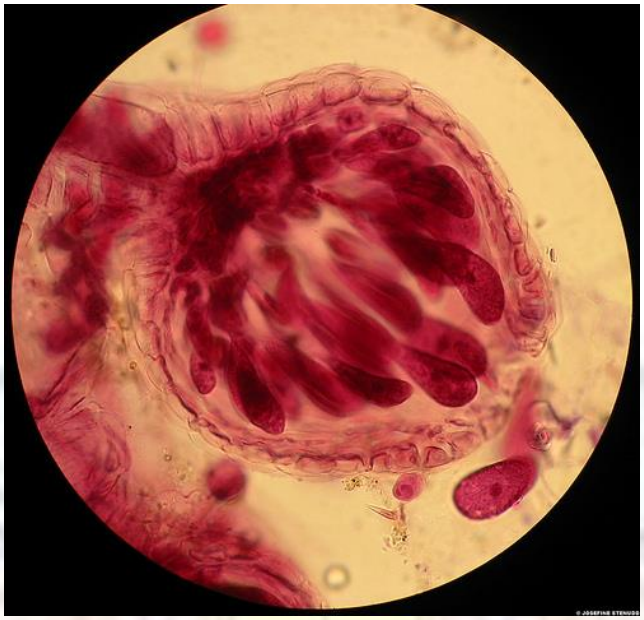


Figure: *Polysiphonia*- Release of carposores from cystocarp

Source: http://farm3.staticflickr.com/2636/4186200422_035e1b1338.jpg

Carpospores slowly swim away, eventually germinating and growing into diploid tetrasporophytes.. These tetrasporophytes bear tetrasporangia and each tetrasporangium bears four tetraspores. The tetraspores can be arranged in a tetrahedral (tetrad), cruciate (crosswise) or a zonate (row) manner.

Figure: Tetrasporangia in *Polysiphonia* bearing tetraspores

Source:http://images.vliz.be/resized/14936_polysiphonia-brodiaei.jpg, http://calphotos.berkeley.edu/imgs/512x768/4444_4444/0311/5529.jpeg

Tetraspores germinate to give rise to male and female gametophytes.

Two different types of sporangia are seen in some higher orders like Ceramiales- one which bear more than four spores, usually in multiples of four. Such sporangia are called polysporangia. In some members of order Rhodymeniales, both tetrasporangia and polysporangia occur on the same plant possibly representing a transition phase between two types of sporangia. Second type are those sporangia in which the cell division is reduced only two spores are produced after meiosis instead of four. Such sporangia are called Bisporangia.

Economic Importance

Commercially, the red algae have been exploited for thousands of years for human consumption and for extraction of polysaccharides – agar and carageenan.

Figure: A few red algae, such as *Porphyra, Rhodymenia* are extensively cultivated as food along the Japanese and Chinese shores.

Source: https://fbcdn-sphotos-e-a.akamaihd.net/hphotos-ak-ash3/p480x480/481220_398421953584563_1955952151_n.png

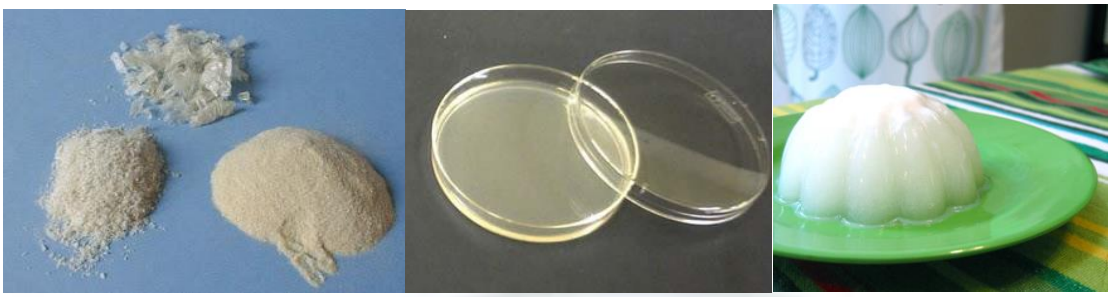
Porphyra (popular Japanese name is *nori*)is a popular flavouring agent, an ingredient of soups and salads, a wrapper for sushi and is eaten with rice and fish. It is a rich source of iodine and some vitamins.

A **B**

Figure: A. Sea weed soup;B. Japanese rice wrapped in sea weed

Source: http://upload.wikimedia.org/wikipedia/commons/thumb/b/bc/Korean_soup-Miyeokguk-01.jpg/300px-Korean_soup-Miyeokguk-01.jpg; http://en.wikipedia.org/wiki/File:Onigiri_at_an_onigiri_restaurant_by_zezebono_in_Tokyo.jpg

Agar is obtained from species of *Gelidium, Gracelaria, Acanthopeltis* and *Pterocladia*.These algae are known as agarophytes. Agarophytes are collected by diving in deep waters and are then dragged off the shore in low tide. The plants are cleaned in fresh water several times and then bleached. The material thus obtained is boiled for several hours and the extract obtained is acidified which is later frozen. On thawing water flows out carrying impurities. Now remaining agar is dried and sold as powder, flakes or cakes. It is used as a nutrient medium for growing bacteria and fungi. Agar is used in food and pharmaceutical industries. Though it is a good laxative, it is more often used as an inert carrier for drugs where a slow release of drugs is required. It is used for gelling and thickening purposes, particularly in canning of fish and meat. It is also used in the manufacture of processed cheese, mayonnaise, puddings, creams, jams and jelly. In the United States, agar is used in the canning industry as a protective agent against the unwanted effects of metals. Agar is a constituent of cosmetics, ointments and lotions and also a stabilizer for emulsions. In addition, agar is the source of agarose, which is widely used in recombinant DNA technology for gel electrophoresis. Japan is the largest producer of agar. Agar-agar is considered a delicacy in japan.



A **B** **C**

Figure: Different forms of agar-A. In powder form; B. gel form ; C. as a constituent of puddings

Source: http://3.bp.blogspot.com/-7zGBs7_Lexk/UTnCv-kSzTI/AAAAAAAACVU/zwJLJb0CP-E/s320/Agar-agar.jpg; http://media-2.web.britannica.com/eb-media/48/124348-004-165E5F45.jpg

Carrageenan is a phycocolloid similar to agar but with a higher ash content, hence required in higher concentrations to form gels. It is obtained mainly from *Chondrus crispus* and *Gigartina stellata* but in small quantities from Eucheuma and Kappophycus. Commercial production is similar to agar although carageenan cannot be purified by freezing.

Figure: Harvesting of *Chondrus crispus* to obtain carageenan

Source: http://tolweb.org/tree/ToLimages/redintro1a.jpg

Commercial usage of carageenan is similar to that of agar except that due to its low gel strength it may not be used for stiffening purposes or in the preparation of media. It is used in toothpastes, cosmetics, instant pudding, sauces and ice creams. It is preferred over agar in stabilization of emulsions in paints, cosmetics and other Pharmaceutical preparations. Carageenans inhibit human immunodeficiency virus (HIV) replication and reverse transcriptionase in vitro. A carageenan based vaginal microbicide called carraguard has been shown to block HIV and other sexually transmitted diseases in vitro (Lee, 2008).

Also visit: http://botany.si.edu/projects/algae/economicuses/redalgae.htm

Polysiphonia

Introduction

The genus *Polysiphonia* derives its name from the polysiphonous nature of its thallus. The central siphons is surrounded by 4-24 pericentral siphons.

Polysiphonia is an exclusively marine member of Rhodophyceae which is found as an epiphyte on plants and lithophyte on rocks in brackish estuaries in the intertidal and sublittoral regions. Most species prefer quite waters whereas some are found in rough or even polluted waters. Some common species found in India are *P.Variegata, P. urceolata* and *P. platycarpa*.

The filamentous thalli are brownish red to dark purple in colour. The filaments branch and re branch to give a feathery appearance. Like most other members of Rhodophyceae, the thalli lack all types of motile cells, have an elaborate sexual apparatus with unparalleled post fertilization changes. Photosynthetic thylakoids occur singly (not stacked in bands) with absence of chlorophyll b.

Figure: Polysiphonous branched thallus of *Polysiphonia*

Source: http://content65.eol.org/content/2010/12/04/04/47595_580_360.jpg, http://content62.eol.org/content/2011/12/29/11/51882_orig.jpg

Thallus

Thallus is heterotrichous with an erect system of branches and a filamentous prostrate system attached to the substratum by means of unicellular rhizoids. The ends of the rhizoids are flattened into lobed discs called haptera.

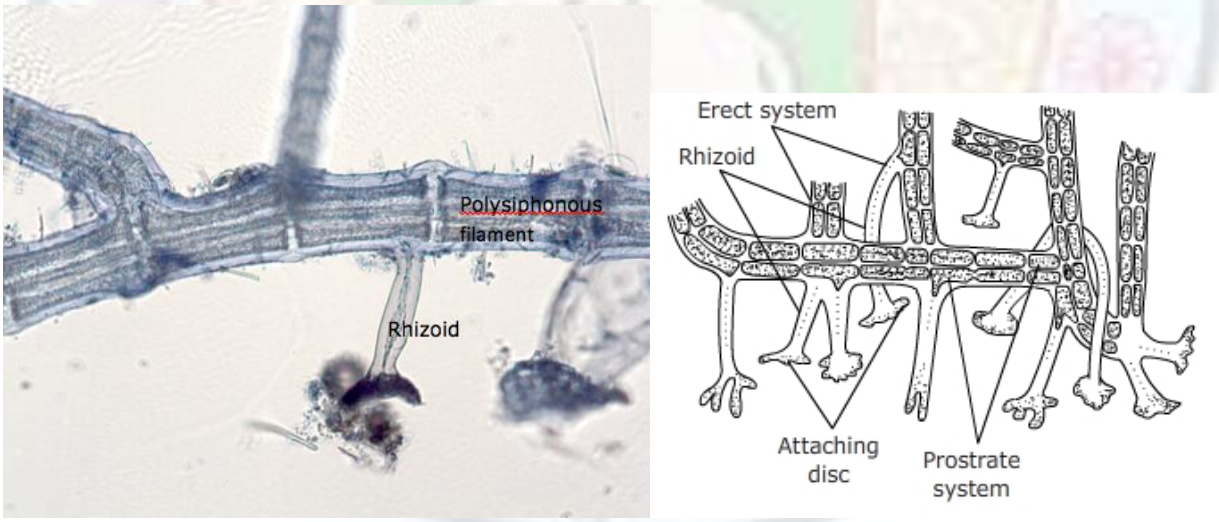


Figure: *Polysiphonia*- The heterotrichous plant body with the prostrate system showing attachment to substratum by means of rhizoids

Source: http://calphotos.berkeley.edu/imgs/512x768/4444_4444/0311/5524.jpeg

Many thalli form thick tufts or dense bushes on substratum. Main filament bears a large number of branches laterally.The branches are of two kinds: **the ordinary branches** which are similar to the main stem and **the trichoblasts.**

- The branches of unlimited growth and are polysiphonous in nature and make up the cental and the pericentral siphon.
- The branches of limited growth - the trichoblasts which are simple hair like and consist of a single uniseriate row of cells. These branches are spirally arranged on the main axis and are deciduous in nature. They may be restricted in their distribution to only certain regions of the plant, are colourless.

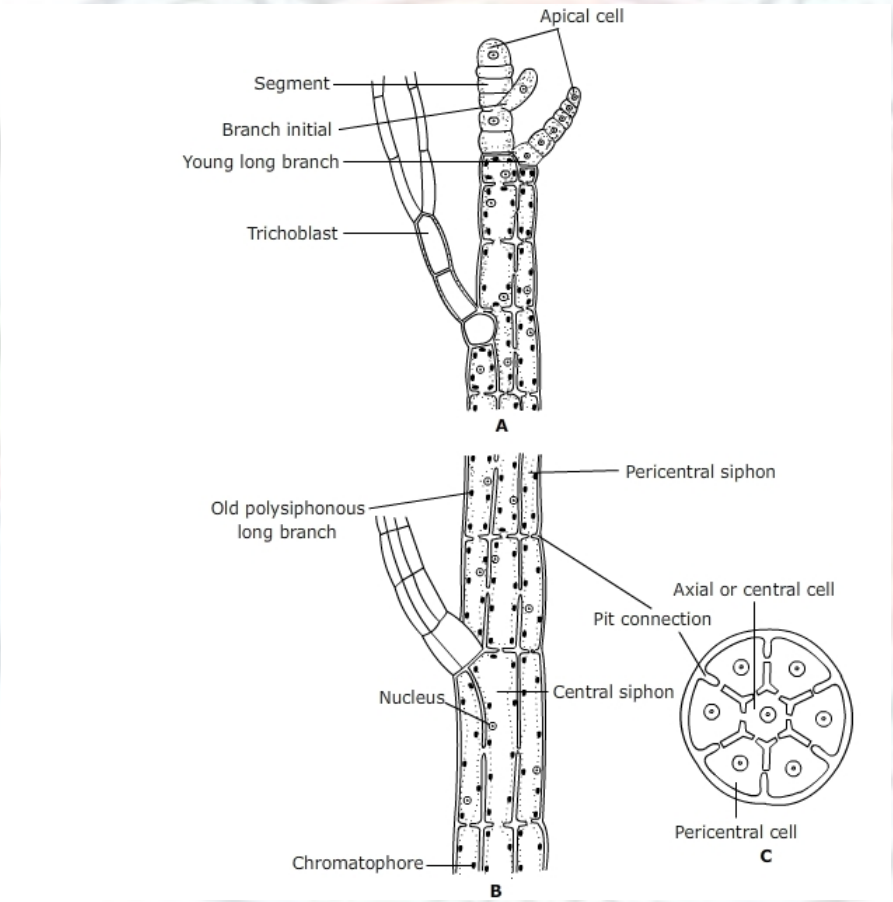


Figure: A-C. Diagrammatic representation of the longitudinal section of the thallus showing the polysiphonous nature. C. Transverse section

Source: Author

Long branches grow as the main axis. On the long branch, 2-5 cells below the apical cell appears a small protrusion which is cut off by a diagonal wall. This is the trichoblast initial

which divides repeatedly to form a dichotomously branched, multicellular structure called as the trichoblast which gradually tapers into a hair like outgrowth. The whole filament is clothed by a gelatinous investment. There is presence of one nucleus and many discoid red chromatophores (chromoplasts) in the cell protoplast.

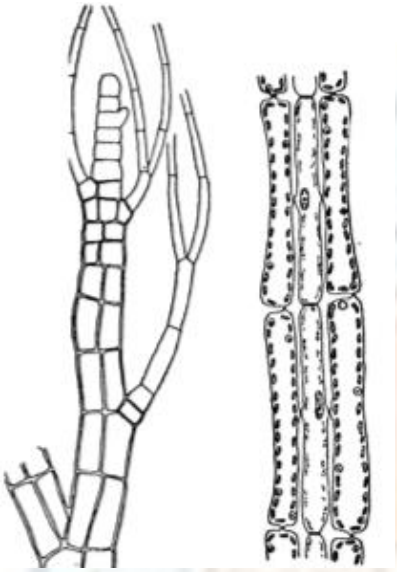


Figure: A. Surface view of a growing apex **B.** Vertical section through a mature portion of the thallus.

Source: Author

Growth takes place by means of a uninucleate, dome-shaped apical cell which divides to form daughter cells. These daughter cells form a number of lateral branches and then ultimately divide into central and pericentral cells. Central cell usually remains uninucleate and is larger than the pericentral cells.The main filament and even the long branches consist of a system of parallel filaments called as siphons varying in number from 4-24. The central cell gives rise to central or the axial filament which is called as the central siphon. The surrounding pericentral cells give rise to the pericentral siphons.

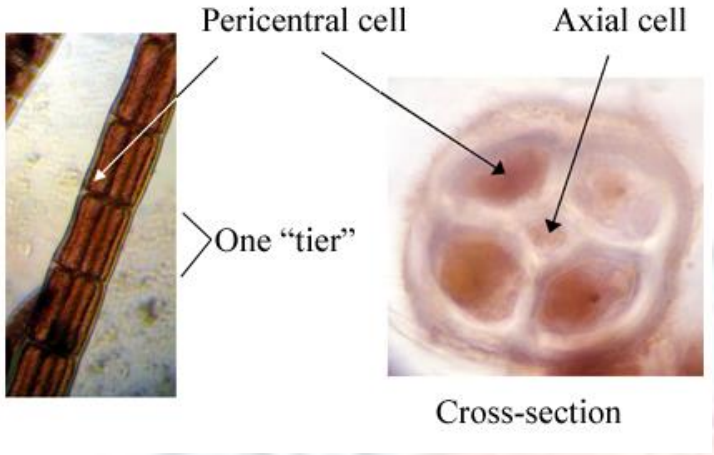


Figure: *Polysiphonia* - Cross section of the polysiphonous filament at the node shows a central axial cell surrounded by the pericentral cells.

Source:http://www.mbari.org/staff/conn/botany/reds/sarah/images/polysiphonousdiagram.jpg

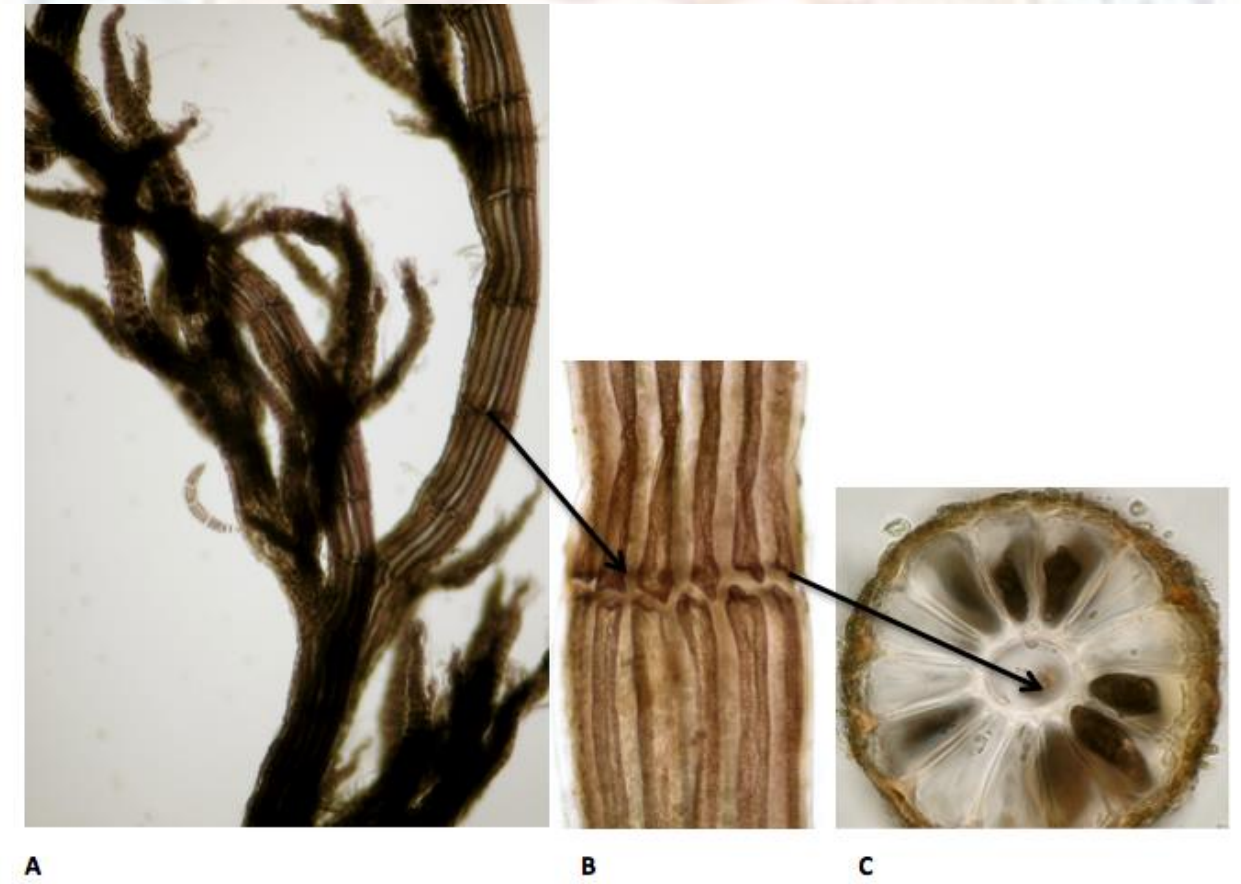


Figure: *Polysiphonia fucoides* - A. whole mount thallus ;B and C magnified view of the node the cross section in C shows the central axial cell surrounded by the pericentral cells.

Source:http://images.marinespecies.org/resized/14943_polysiphonia-fucoides.jpg, http://images.marinespecies.org/resized/14945_polysiphonia-fucoides.jpg

Pit connections occur between adjoining central cells and also between central and pericentral cells, a characteristic feature of all red algae.

Reproduction

As mentioned earlier, the gametophyte is concerned with sexual reproduction. The plants are heterothallic or dioecious which means that male and female sex organs are borne on different plants. In *Polysiphonia*, male and female gametophytes are morphologically similar, hence isomorphic alternation of generations. The male gametophyte bears the male sex organ or the spermatangium and the female gametophyte bears the female sex organ or the carpogonium.

Spermatangia: These are borne in dense clusters in compact cone shaped structures on monosiphonous branches called the trichoblasts.

Figure: Fertile branch - male trichoblasts

Source:http://upload.wikimedia.org/wikipedia/commons/3/30/Polysiphonia_spermatangia_WM.jpg,http://www.biologie.uni-hamburg.de/b-online/library/webb/BOT311/Rhodophyta/PolysiphoniaAnther.jpg

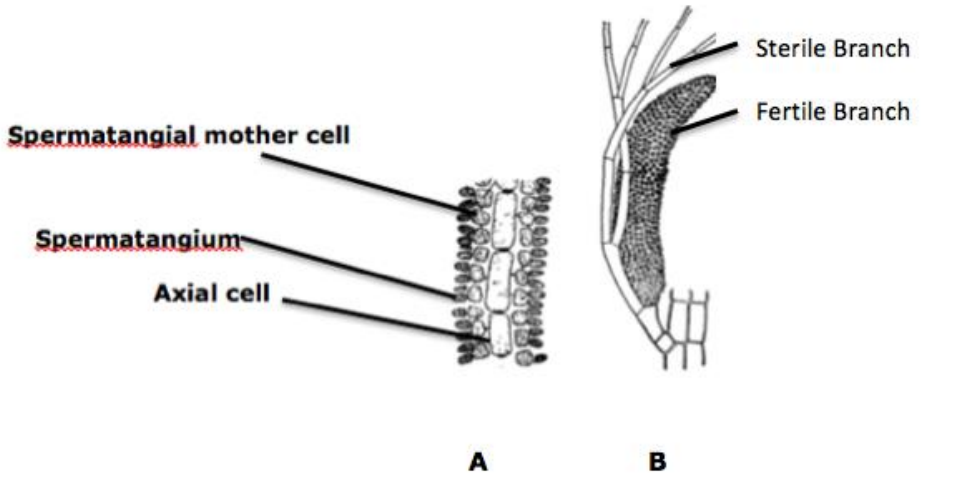


Figure: A. Section of fertile branch (trichoblast) with the spermatangial mother cell bearing the spermatangium and B. Whole mount male trichoblast

Source: Author

Trichoblasts are present near the apices of the male branches. Each trichoblast has a many celled fertile portion supported by a stalk of two cells.The fertile portion of the trichoblast bears the spermatangia which are spherical or oblong in shape. These appear as pale or white dots or patches. Spermatangia are unicellular with a colourless cytoplasm and a large nucleus. Cell wall is thick and differentiated into three distinct layers. The outermost layer is deeply staining, followed by middle gelatinous layer and the innermost being refractive in nature. The uninucleate protoplast of the spermatangium produces a single male cell called the spermatium.The spermatium is unicellular, spherical, non-motile and colourless. It is transported through a narrow apical slit in the spermatangial wall. The spermatia are transported by the water current to the female sex organs.

Carpogonium: It is situated at the tip of reduced 3-4 celled branch (trichoblast) called the carpogonial branch or the carpogonial filament. Carpogonium is a flask shaped structure with a swollen base and a long tubular neck called the trichogyne. The trichogyne functions as a receptive organ.

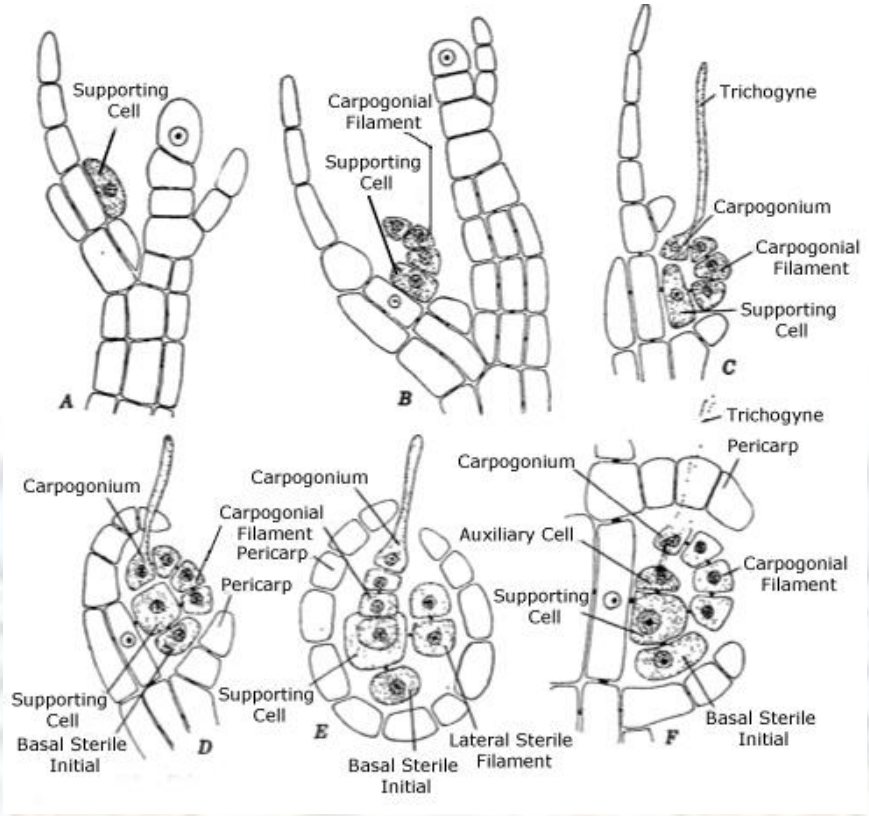


Figure: Stages in Formation of Carpogonium and auxillary cell from supporting cell

Source: ILLL In house

Fertilization: Liberated spermatia are carried by the seawater to the female reproductive structures. As the spermatium comes in vicinity of carpogonium, it gets attached to the trichogyne. Common walls dissolve at the point of attachment. The male nucleus enters the trichogyne and slowly moves towards the base of the carpogonium. First it comes to lie by the side of the female nucleus and later fuses with it to accomplish fertilization. The fusion nucleus is a diploid structure which lies at the base of the carpogonium.

Post fertilization changes: A series of changes occur in the sexual apparatus leading to development of carposporophyte. The cell just below the carpogonium is called as the auxillary cell. This is formed by budding of the supporting cell. Auxillary cell develops a tubular connection with the base of the carpogonium and possesses a haploid nucleus. At this stage the diploid nucleus at the base of the carpogonium divides mitotically to form two daughter nuclei. One of these diploid nuclei migrates to the auxillary cell. The haploid nucleus of auxillary cell now degenerates and even the carpogonial branch begins to shrink. Outgrowths of pericentral cells adjacent to the supporting cells form an envelope around the

developing carposporophyte. The migrated diploid nucleus in the auxillary cell undergoes mitosis. One of the daughter nuclei remains in the auxillary cell whereas the other moves to a small lateral outgrowth of the auxillary cell. This outgrowth is the gonimoblast initial which later seperates from the auxillary cell by means of a septum. This gonimoblast initial grows into a number of short threads called the gonimoblast filaments which ultimately form a compact mass. The cells at the tips of the gonimoblast filaments develop into pear shaped carposporangia. The diploid protoplasm of of the carposporangium with its diploid nucleus develops into a single, diploid carpospores. The carposporangia bearing the carpospores are enveloped by a sheath of pericarp (two layers) to form an urn-shaped fruiting body called as the cystocarp. The cystocarp is partly diploid and partly haploid because the carpospores along with the carposporangium are diploid and the two layered pericarp is haploid. At maturity the carpospores float out through the opening of the cystocarp (ostiole) and are carried away by the water currents.

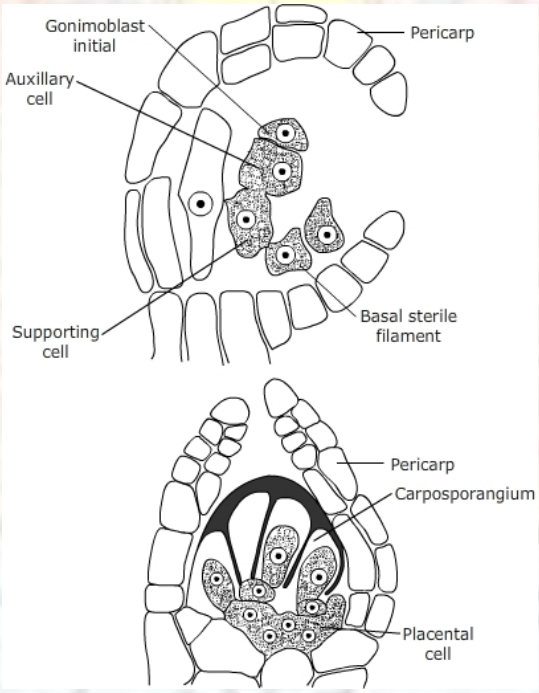


Figure: Developmental stages in formation of cystocarp

Source: ILLL Inhouse

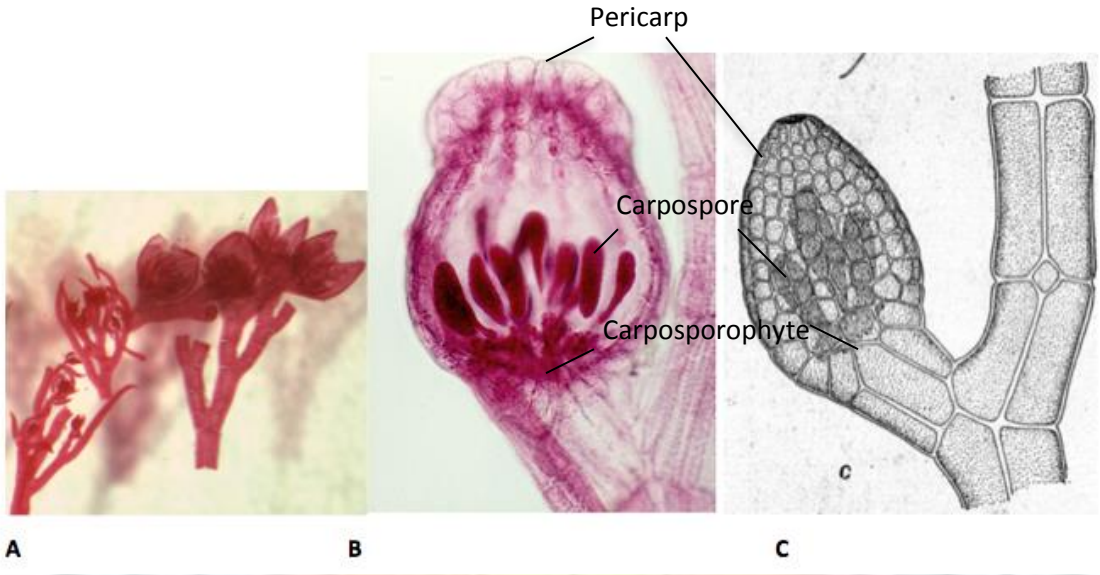


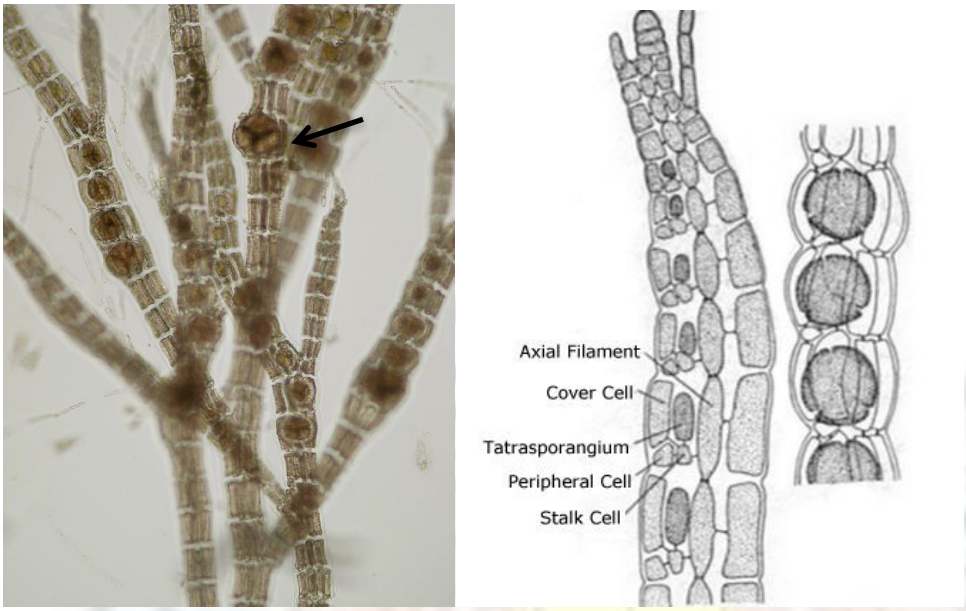
Figure: A. Carpogonial branch with carposporangia

B. Carpospores and carposporangium jointly constitute the cystocarp or carposporophyte

C. Cystocarp with its opening or the ostiole

Source:http://farm3.static.flickr.com/2538/4166830529_7247019ab5_o.jpg, http://upload.wikimedia.org/wikipedia/commons/7/70/Polysiphonia_cystocarp_WM.jpg

On coming in contact with any solid substratum, the naked diploid carpospores secretes a wall around itself and attaches to the substratum. The carpospores undergoes repeated mitotic divisions to ultimately form a diploid plant. This is the tetrasporophyte of *Polysiphonia* which is a free living individual with thallus similar to that of the gametophyte but is vegetative in nature. Tetrasporophyte is a diploid individual unlike the gametophyte and produces haploid tetraspores. The fertile branches bearing the tetrasporangia become swollen and twisted at maturity.The tetrasporangia are spherical and diploid and develop from the pericentral cells. In each tier of pericentral cells only one tetrasporangium develops. The pericentral cell destined to become a tetrasporangium is smaller than all other cells in the same tier. It divides into an outer half which gives rise to two cover cells and an inner half forming the sporangial mother cell. A transverse wall divides the sporangial mother cell into a lower stalk cell and an upper tetrasporangial cell. The diploid nucleus of the tetrasporangium undergoes meiosis to form four haploid daughter nuclei. These daughter nuclei are arranged tetrahedrally and give rise to four tetraspores.



A **B**

Figure: A. Branch of tetrasporophyte with tetrasporangia. Tetrahedrally arranged tetraspores can also be seen (arrow). B. Section of the tetrasporophyte with young tetrasporangia .

Source: http://images.vliz.be/resized/14936_polysiphonia-brodiaei.jpg

Also visit:http://www.vcbio.science.ru.nl/public/Final-Images/PL_Final685z_001-050/PL0047_685zPolysiphoniaTetradeOverviewDetail.jpg

Ultimately, the sporangial wall ruptures and the tetraspores are liberated. Tetraspores germinate without any period of dormancy to give rise to gametophytes concerned with the sexual reproduction.

Life cycle: Cytologically, the life cycle of *Polysiphonia* is Triphasic diplobiontic as there are both haploid and diploid individuals present. Of the three phases in the life cycle, one is haploid and two phases are diploid. Hence, the life cycle is diplodiplohaplontic or diplobiontic.

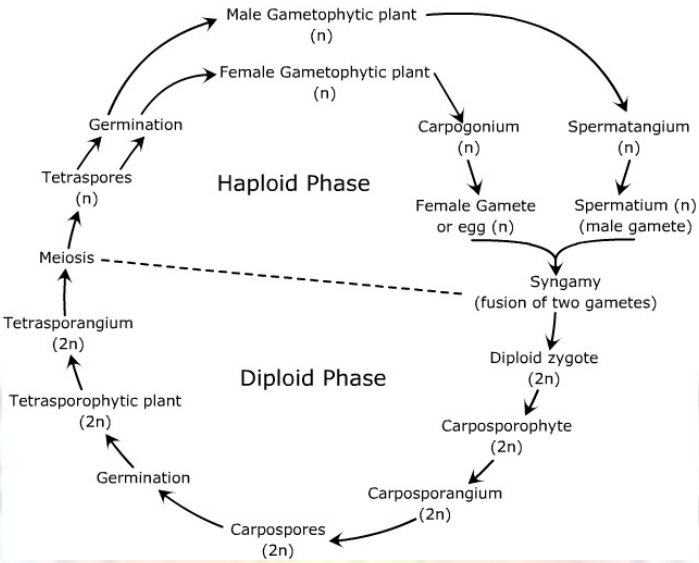


Figure: Haplodiplobiontic (Triphasic) life cycle of *Polysiphonia*

Source: Author

Also visit for images:
http://comenius.susqu.edu/biol/202/archaeplastida/rhodoplantae/rhodophyta/polysiphonia-lc-lee-a.jpg,

http://plantphys.info/organismal/lechtml/images/polysiphonia.gif

http://www.resnet.wm.edu/~mcmath/bio205/diagrams/botun05a.gif

Taxonomic position

Sub-division : Algae

Class : Rhodophyceae

Sub- class : Florideae

Order : Ceramiales

Family : Rhodomelaceae

Genus : *Polysiphonia*

The plants fall under sub-division algae as the plant body is thalloid and there is presence of cholorophyll in the cells. The cell wall is made up of cellulose and not mucopolysaccharides as is the case in fungi.

Presence of red to dark purple chromatophores places these plants in class Rhodophyceae. Other features like presence of floridoside as reserve food material, non-motile male gametes, female reproductive structure with a trichogyne are also very typical of Rhodophyceae.

Filamentous thallus with pit-connections, highly specialized carpogonium and cells with more than one chromatophores or chloroplasts are characteristic features of Sub-class Florideae.

Polysiphonous multiaxial filaments with cortications place these plants in order Ceramiales.In this order, the spermatangia are in clusters and trichoblasts are present.

Main axis surrounded by pericentrals and branches delicate in nature are significant features of Rhodomelaceae.

Typical feature of *Polysiphonia* is presence of tetrasporangia borne singly.

Summary

Red algae constitute a large group of eukaryotic, multicellular algae commonly called as the sea weeds. Most Rhodophyceae members are filamentous or foliaceous and grow attached by means of rhizoids or holdfasts to rocks, shells, other algae or sea grasses. Many genera are parasitic or even epiphytic on other genera and establish pit connections with them. Though the thalli are really large, there is hardly any differentiation or specialization amongst the cells. Like Cyanobacteria, red algae contain r-phycoerythrin and r-phycocyanin pigments aggregated into phycobilisomes.The red colour of the thallus is attributed to the presence of r-phycoerythrin, though the main photosynthetic pigment remains chlorophyll a. the actual quantity of the pigments in a thallus varies with the depth occupied. Excess of photosynthates are stored in the form of floridean starch in the cytoplasm.

Red algae are different from all other groups of algae in lacking all motile stages in development. Chloroplasts is a double membrane structure with no chloroplast endoplasmic reticulum and contains single thylakoid per band. Phycobilisomes are present on the surface of the thylakoids. Cell wall is mainly composed of cellulose. Cells often get impregnated with lime and hence appear stony.

Triphasic life cycle is divided into gametophyte, carposporophyte and tetrasporophyte.The gametophyte is the sexual stage which produces the gametes. A diploid zygote is formed by the union of two haploid gametes and eventually gives rise to a carposporophyte after undergoing a few complex stages. Carposporophyte produces diploid carpospores which germinate to produce a diploid tetrasporophyte. The tetrasporophyte is equivalent to a regular sporophyte and undergoes meiosis to produce tetraspores. These are haploid spores which germinate to form haploid gametophyte. Life cycle in general is Diplobiontic.

Glossary

Monopodial branching: A type of branching in which new branches arise below the growing point and remain subsidiary or secondary to the main axis. The main axis grows uninhibited and indefinitely.

Epiphyte: One plant living on another plant and is not attached to any kind of substratum.

Parasite: It is a heterotrophic organism that derives all its nutrients from a living host.

Galactose: It is a hexose sugar found in plants. Oxidation of galactose yields galacturonic acid.

Heterotrichous: Thallus having both a prostrate and an erect system.

Bioluminiscence: Emission of light from living organisms as a result of internal chemical reactions orre-emission of absorbed energy.

Proplastid: A small plastid with rudimentary internal structure.

Polysaccharide: An energy storage molecule of high molecular weight. It is a polymer of monosaccharides.

Siphonaceous: Indicating a tubular growth habit

Exercises

1. Fill in the blanks:

i. Absence of -------- in the Life cycle is a common feature between Cyanophyceae and Rhodophyceae.

ii. Phycobilisomes are present on----------.

iii. ---------- is the reserve food material found in Rhodophyceae.

iv. ---------- and ---------- are the two most important accessory pigments in Red algae.

2. Indicate which of the following are true or false:

i. *Polysiphonia* has pit connections in the thallus.

ii. Asexual reproduction takes place by means of zoospores in red algae.

iii. Red algae are called stoneworts.

iv. Tetrasporophyte is equivalent to sporophyte.

3. Explain briefly:

i. Pit connections

ii. Carpogonium

iii. Economic importance of Rhodophyceae

iv. A Rhodophycean cell

4. Compare the three different phases in the Life cycle of Rhodophyceae.

5. Draw a well-labeled diagram of the Life cycle of *Polysiphonia.*

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Links

http://tolweb.org/Rhodophyta

http://www.marbef.org/modules.php?name=Photogallery&album=58

http://eol.org/search?q=polysiphonia&search=Go

http://www.ucmp.berkeley.edu/protista/rhodophyta.html

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http://www.microscopy-uk.org.uk/mag/indexmag.html?http://www.microscopy-uk.org.uk/mag/artmar99/red.html

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