

# A New Approach to the Classification of Algae

**Mustafa Shameel**  
 Department of Botany,  
 University of Karachi,  
 Karachi-75270, Pakistan.

A new classification of algae up to the ordinal level, based on five kingdoms of living organisms, has been suggested in this paper, wherein algae are distributed in three kingdoms and include 19 phyla, 31 classes and 107 orders. Delineation of these groups is based on the micromorphological, ultrastructural and phycochemical characteristics of algae. As a result, three new phyla i.e. Volvocophyta, Porphyridiophyta and Vaucheriophyta, ten new classes i.e. Chroocophyceae, Nostocophyceae, Volvocophyceae, Desmidiophyceae, Porphyridiophyceae, Siphonocladophyceae, Vaucheriophyceae, Dictyophyceae, Nemaliophyceae and Ceramiophyceae, and four new orders i.e. Glaucocystales, Pelagomonadales, Vischeriales and Vacuolariales have been created. Typified names are preferred to descriptive names of various taxa. A comparison has also been made between various phyla regarding their diagnostic characters.

**Keywords:** Algae, classification, phyla, classes, orders.

## Introduction

Algae are very simple, water-loving, autotrophic organisms, which have no sterile layer of jacket-cells around their reproductive organs and lack true embryogenesis. As primary producers, they are an important component of aquatic ecosystem, being inhabitants of moist, freshwater, brackish water and marine environments of our biotope. They may have antibiotic e.g. bactericidal, antiviral, larvicidal and vermifuge as well as blood anticoagulant, laxative and convalescent natural products in their thalli, possessing a variety of remedial properties in them. Algae include heterogenous and polyphyletic assemblage of individuals and are distributed in three kingdoms

i.e. Monera, Protista and Protoctista<sup>1</sup>. They have been variously classified in the past purely on the basis of general and cellular morphology, anatomy and reproduction. Now, several other criteria have been discovered to classify them e.g. cellular organisation, nature of chloroplast endoplasmic reticulum (CER), flagellation, electron microscopic structures, cell-wall constituents, pigmentation, biochemical properties, secondary metabolites and above all their nucleotide sequencing. As a result of accumulating information, several attempts have been made in the last quarter of the past century to classify algae<sup>2</sup>, but further progress in this respect demands a better and more natural classification.

## Proposed Classification

On the basis of micromorphological, ultrastructural and phycochemical characteristics, an attempt has been made to classify algae up to the ordinal level as follows:

**A. Kingdom Monera:** Individuals with procaryotic cellular organization.

**I. Phylum cyanophyta (blue-green algae):**  
 Pigmentation: chlorophyll a only, echinenone and myxoxanthophyll, no lutein, phycobiliproteins; flagellation: no flagella; storage product: glycogen, cell-wall constituent: peptidoglycan; no true nucleus, no plastids, no cell organelles, no sexual reproduction.

**i) Class Chroocophyceae:** Unicellular, palmelloid or colonial forms.

1. **Order Chroococcales:** Cells loosely bound into gelatinous, irregular colonies; reproduction by cell division or endospores; type: Chroococcaceae, *Chroococcus*.

2. **Order Chaemosiphonales:** Lithophytes or epiphytes with a thallus showing polarity; reproduction: endospores or exospores, type: Chaemosiphonaceae, *Chaemosiphon*.

ii) **Class Nostocophyceae:** Filamentous forms.

1. **Order Pleurocapsales:** Heterotrichous, filamentous forms, lacking heterocysts; no hormogonia, reproduction: endospores; type: Pleurocapsaceae, *Pleurocapsa*.

2. **Order Nostocales:** Filamentous forms with heterocysts, no heterotrichy, no true branching, reproduction: hormogonia and akinetes; type: Nostocaceae, *Nostoc*.

3. **Order Stigonematales:** Heterotrichous filaments with heterocysts and true branching; pit-connections between adjacent cells; reproduction: hormogonia, hormocysts and akinetes; type: Stigonemataceae, *Stigonema*.

II. **Phylum prochlorophyta (green pro-caryotes):** Pigmentation: chlorophyll a and b, zeaxanthin and cryptoxanthin, no phycobiliprotein; flagellation: no flagella; storage product: monogalactolipid; cell-wall constituent: peptidoglycan; no true nucleus, no plastids, no cell organelles, no sexual reproduction.

i) **Class Prochlorophyceae:** Same as above.

1. **Other Prochlorales:** Same as above; type: Prochloraceae, *Prochloron*.

B. **Kingdom Protista:** Eucaryotic cells with solitary or colonial, unicellular organization.

1. **Phylum glaucophyta (endosymbiotic algae):** Pigmentation: chlorophyll a only, no echinenone and myxoxanthophyll, phycobiliproteins; flagellation: two subterminal, heterokontic flagella; storage product: starch; cell-wall constituent: cellulose; individuals having endosymbiotic blue-green algae in the cytoplasm instead of chloroplasts, exhibiting syncyanosis.

i) **Class Glaucophyceae:** Same as above.

1. **Order Glaucocystales:** Same as above type: Glaucocystaceae, *Glaucocystis*.

II. **Phylum volvocophyta (green micro-algae):** Pigmentation: chlorophyll a and b; flagellation: two or four, terminally attached, acronematic, isokontic flagella; storage product: starch found inside chloroplast; cell-wall constituent: glycoproteins, acidic polysaccharides; unicellular or colonial algae.

i) **Class Micromonadophyceae:** Primitive green flagellates with interzonal mitotic spindles that are persistent during cytokinesis; scales when present outside of the cell.

1. **Order Micromonadales:** Same as above; type: Micromonadaceae, *Micromonas*.

ii) **Class Volvocophyceae:** Unicellular or colonial algae; collapse of the interzonal mitotic spindle before new cross-walls are formed by a phycoblast.

1. **Order Tetraselmidales:** Four flagella attached at the base of an apical pit; cells surrounded by a theca formed by the coalescence of small scales, rhizoplasts persistent; type: Tetraselmidaceae, *Tetraselmis*.

2. **Order Volvocales:** Vegetative cells flagellated and motile; type: Volvocaceae, *Volvox*.

3. **Order Tetrasporales:** Colonies with immobile vegetative cells capable of cell division; pseudocilia may be present; type: Tetrasporaceae, *Tetraspora*.

4. **Order Chlorococcales:** Nonmotile unicells or colonies; division of the cells gives rise to zoospores or gametes; type: Chlorococcaceae, *Chlorococcum*.

5. **Order Chlorellales:** Lack the capacity for zoospore formation; only a few produce flagellated gametes; reproduction restricted to nonmotile autospores or autocolonies; type: Chlorellaceae, *Chlorella*.

6. **Order Chlorosarcinales:** Daughter cells retained within parent cell-wall; no plasmodesmata; type Chlorosarcinaceae, *Chlorosarcina*.

iii) **Class Desmidiophyceae:** (desmids): Unicellular or occasionally filamentous but without fragmentation; sexual reproduction by conjugation.

1. **Order Mesotaeniales** (saccoderm desmids): Cell-walls without pores; no new semi-cell formed in cell-division; type: Mesotaeniaceae, *Mesotaenium*.

2. **Order Desmidiates** (placoderm desmids): Cell-walls with pores; new semi-cell formed in cell-division; type: Desmidiaceae, *Desmidium*.

### III. Phylum euglenophyta (euglenoids):

Pigmentation: chlorophyll a and b; flagellation: two basal bodies, one or two emergent, apical flagella, one with a spiralled row of fibrillar hairs; storage product: paramylon; cell-wall constituents: 80% protein, 11.6% lipid, 8.4% carbohydrate, proteinaceous pellicle in strips under the plasma membrane; mesocaryotic nucleus, characteristic type of cell division; no sexual reproduction.

#### i) Class Euglenophyceae: Same as above.

1. **Order Heteronematales**: Two emergent flagella, the longer one directed anteriorly and the shorter one directed posteriorly during swimming, special ingestion organelle present; type: Heteronemataceae, *Heteronema*.

2. **Order Eutreptiales**: Two emergent flagella, one directed anteriorly and the other laterally or posteriorly during swimming; no special ingestion organelle; type: Eutreptiaceae, *Eutreptia*.

3. **Order Euglenales**: Two flagella, only one emerges from the canal; no special ingestion organelle; type: Euglenaceae, *Euglena*.

### IV. Phylum dinophyta (dinoflagellates):

Pigmentation: chlorophyll a and  $c_2$ , peridinin and neoperidinin; flagellation: two laterally inserted, heterokontic flagella, longitudinal flagellum is small, straight and smooth, transverse flagellum is long, wavy, encircling and covered with 0.5  $\mu\text{m}$  long and 10 nm wide hairs; storage product: starch found in cytoplasm; cell-wall: cellulosic plates having flattened vesicles, which constitute thecal structure, commonly divided into an epicone and a hypocone by a girdle; dinocaryotic nucleus.

#### i) Class Dinophyceae: Same as above.

1. **Order Prorocentrales**: Cell-wall divided vertically into two halves; no girdle; two flagella borne at cell-apex; type: Prorocentraceae *Prorocentrum*.

2. **Order Dinophysiales**: Cell-wall divided

vertically into two halves; cells with elaborate extensions of theca, type: Dinophysaceae, *Dinophysis*.

3. **Order Peridinales**: Motile cells with an epicone and a hypocone separated by girdle; type: Peridiniaceae, *Peridinium*.

4. **Order Dinocapsales**: Palmelloid organisms with a temporary motile stage; type: Dinocapsaceae, *Dinocapsa*.

5. **Order Dinococcales**: Unicellular, nonmotile organisms with no vegetative cell-division and with new cells formed by production of zoospores; type: Dinococcaceae, *Dinococcus*.

6. **Order Dinotrichales**: Immobile cells joined end to end in filaments; type: Dinotrichaceae, *Dinotrix*.

### V. Phylum cryptophyta (cryptoflagellates):

Pigmentation: chlorophyll a and  $c_2$ , diatoxanthin, phycobiliproteins; flagellation: two apically or laterally attached, pantonematic flagella at the base of a depression; storage product: starch found in grains between inner membrane of CER and chloroplast envelope; cell-wall constituent: polysaccharide periplast found inside plasma membrane; nucleomorph present between inner and outer membranes of CER; projectiles called ejectisomes present.

#### i) Class Cryptophyceae: Same as above.

1. **Order Cyathomonadales**: Colourless cells with no plastids, multiple periplast plates; flagella with fibrillar hairs; rhizostyle short; type: Cyathomonadaceae, *Cyathomonas*.

2. **Order Cryptomonadales**: Plastids present; periplast containing multiple plates; flagella usually with two rows of microtubular hairs on one flagellum and a single row of such hairs on the other; rhizostyle short; type: Cryptomonadaceae, *Cryptomonas*.

3. **Order Thecomonadales**: Plastids present; periplast containing a single plate; flagella usually with a single row of microtubular hairs on each flagellum; rhizostyle long; type: Thecomonadaceae, *Thecomonas*.

VI. Phylum chrysophyta (golden-brown algae): Pigmentation; a,  $c_1$  and sometimes  $c_2$ , fucoxanthin; flagellation: two, anterior tinsel and posterior whiplash flagella; storage product: chrysolaminarin; cell-wall: radially or bilaterally

symmetrical, silica scales; statospores enclosed in a silicified wall with a terminal pore.

i) **Class Chrysophyceae:** Chlorophyll a,  $c_1$  and  $c_2$ ; two flagella inserted into the cell, perpendicular to each other, one photoreceptor on the short flagellum; contractile vacuole in the anterior portion of the cell, eyespot in the anterior portion of the chloroplast; radially or biradially symmetrical, silica scales (if present).

1. **Order Bicosoecales:** Heterokont flagellates, having four microtubular flagellar roots; chloroplast entirely absent; organic cysts, when formed; type: Bicosoecaceae, *Bicosoeca*.

2. **Order Ochromonadales:** Two unequal flagella arising from a depression in the anterior portion of the cell; type: Ochromonadaceae, *Ochromonas*.

3. **Order Chromulinales:** Single emergent flagellum, while second flagellum reduced to a short stub; type: Chromulinaceae, *Chromulina*.

4. **Order Parmales:** Cells with siliceous walls, composed of five or eight plates; type: Parmaceae, *Triparma* / *Tetraparma*.

5. **Order Hibberdiales:** Two stages in life-history: immobile capsoid-like and free-swimming single-celled flagellate; flagellar roots do not form a loop under second flagellum; type: Hibberdiaceae, *Hibberdia*.

6. **Order Hydrurales:** Capsoid or parenchymatous, crustose disks, gelatinous thalli; tetrahedral zoospores; type: Hydruraceae, *Hydrurus*.

7. **Order Chrysomeridales:** Motile naked cells with laterally inserted flagella (similar to Phaeophyta) and an eyespot; type: Chrysomeridaceae, *Chrysomeris*.

ii) **Class Dictyochophyceae:** Chlorophyll a,  $c_1$  and  $c_2$ ; tentacles or rhizopodia on basically amoeboid vegetative cells.

1. **Order Rhizochromulinales:** Unicells with tentacles; type: Rhizochromulinaceae, *Rhizochromulina*.

2. **Order Pedinellales:** (choanoflagellates): Single emergent flagellum that has a strengthening band and is wavelike, similar to the transverse flagellum of the dinoflagellates; type: Pedinellaceae, *Pedinella*.

3. **Order Dictyochales** (silicoflagellates): Cells with an external silicified skeleton; type: Dictyochaceae, *Dictyocha*.

iii) **Class Synurophyceae** (flagellated diatoms): Chlorophyll a and  $c_1$ ; insertion of the flagella into the cell approximately parallel to each other; two photoreceptors, one near the base of each flagellum; contractile vacuole in the posterior of the cell; no eyespot; bilaterally symmetrical silica scales common.

1. **Order Synurales:** Same as above; type: Synuraceae, *Synura*.

iv) **Class Pelagophyceae** (brown-tide algae): Unicells, very small (3-5  $\mu\text{m}$ ), ultraplankton; a single tinsel flagellum may or may not be present; peculiar sequences of small-subunit RNA nucleotides.

1. **Order Pelagomonadales:** Same as above; type: Pelagomonadaceae, *Pelagomonas*.

VII. **Phylum Prymnesiophyta** (haptophytes): Pigmentation: chlorophyll a,  $c_1$  and  $c_2$ , fucoxanthin; flagellation: two whiplash flagella with a haptoneuma in between; storage product: chrysolaminarin found in vesicles in cytoplasm; cell-wall: encrusted with  $\text{CaCO}_3$  in the form of calcites rarely aragonite; scales common outside cell.

i) **Class Prymnesiophyceae:** Same as above.

1. **Order Isochrysidales:** Cells with no or only a rudimentary haptoneuma, flagella whiplash and isokontic; type: Isochrysidaceae, *Isochrysis*.

2. **Order Prymnesiales:** Cells with a recognizable haptoneuma; flagella whiplash and isokontic; type: Prymnesiaceae, *Prymnesium*.

3. **Order Coccoisphaerales** (coccolithophorids): Cells covered with coccoliths in at least one part of the life-cycle, haptoneuma present; flagella whiplash and isokontic; type: Coccoisphaeraceae, *Coccoisphaera*.

4. **Order Pavlovaes:** Haptoneuma present, two unequal flagella often covered with hairs and deposits; type: Pavlovaceae, *Pavlova*.

VIII. **Phylum Bacillariophyta** (diatoms): Pigmentation: chlorophyll a,  $c_1$  and  $c_2$ , fucoxanthin; flagellation: one posterior tinsel flagellum on sperm

only; storage product: chrysolaminarin found in vesicles in cytoplasm; cell-wall constituent: silica in bipartite; sculptured frustule, outer epitheca and inner hypotheca.

i) **Class Bacillariophyceae:** Same as above.

1. **Order Biddulphiales** (centric diatoms): Radial or gonoid ornamentation; many chloroplasts; no raphe; resting spores formed, motile spermatozoids with a single tinsel flagellum; sexual reproduction by oogamy; type: Biddulphiaceae, *Biddulphia*.

2. **Order Bacillariales** (pennate diatoms): Pennate or trilettoid ornamentation; one or two chloroplasts; raphe possibly present with gliding; no flagellated spermatozoids, sexual reproduction by conjugation; type: Bacillariaceae, *Bacillaria*.

**IX. Phylum xanthophyta (yellow-green microalgae):** Pigmentation: chlorophyll a only, diadinoxanthin, heteroxanthin, no fucoxanthin; flagellation: anterior tinsel and posterior whiplash flagellum; storage product:  $\beta$ -1, 3 linked glucan similar to paramylon and lipid; eyespot in chloroplast; cell-wall: composed of two overlapping halves, cellulose, glucuronic acid.

i) **Class Xanthophyceae:** Same as above.

1. **Order Heterochloridales:** Organisms with flagellated or amoeboid vegetative cells; type: Heterochloridaceae, *Heterochloris*.

2. **Order Heterogloales:** Palmelloid organisms (in colonies of indefinite shape) with immobile vegetative cells that can return directly to motile cells; type: Heterogloeaceae, *Heterogloea*.

3. **Order Mischococcales:** Non-filamentous organisms with immobile vegetative cells that cannot change directly to motile cells but can produce zoospores by differentiation of a mother cell; type: Mischococcaceae, *Mischococcus*.

**X. Phylum eustigmatophyta (eustigmatophytes):** Pigmentation: chlorophyll a only, violaxanthin and vaucherixanthin, no antheraxanthin; flagellation: one or two, anterior tinsel and posterior whiplash flagellum (commonly reduced), t-shaped flagellar melting at the base of tinsel flagellum; eyespot large and outside chloroplast, stalked pyrenoids; cell wall constituent: polysaccharides; zoospores naked and somewhat amoeboid.

i) **Class Eustigmatophyceae:** Same as above.

1. **Order Vischeriales:** Same as above; type: Vischeriaceae, *Vischeria*.

**XI. Phylum raphidophyta (chloromonads):** Pigmentation: chlorophyll a and c<sub>1</sub>, fucoxanthin; flagellation: anterior tinsel and posterior whiplash flagellum, sometimes possess projectiles; mucocysts in the peripheral cytoplasm; many small chloroplasts; cell wall: surrounded by a thick gelatinous matrix.

i) **Class Raphidophyceae:** Same as above.

1. **Order Vacuolariales:** Same as above; type: Vacuolariaceae, *Vacuolaria*.

**XII. Phylum porphyridiophyta (red microalgae):** Pigmentation: chlorophyll a and d, phycobiliproteins; flagellation: no flagella; storage product: floridean starch; cell-wall constituents: polysaccharides and amorphous mucilage, no cellulose microfibrils; one large or a few plastids, with central pyrenoids.

i) **Class Porphyridiophyceae:** Same as above.

1. **Order Porphyridiales:** Unicells or multicellular algae that are held together by mucilaginous walls; type: Porphyridiaceae, *Porphyridium*.

**C. Kingdom Protocista:** Coenocytic or simple multicellular organisation.

**I. Phylum chlorophyta (green-algae):** Pigmentation: chlorophyll a and b, lutein; flagellation: 2 or 4 terminal, whiplash, isokontic flagella; storage product: starch found inside chloroplast; cell-wall constituent: cellulose, mannan, xylan.

i) **Class Ulvophyceae:** Filamentous or thalloid algae, normal cell division, sexual reproduction by iso-, aniso- or oogamy.

1. **Order Klebsormidiales:** Unbranched filaments without holdfasts; no plasmodesmata; zoospores naked and released through a pore in the cell-wall; type: Klebsormidiaceae, *Klebsormidium*.

2. **Order Ctenocladales:** Filamentous marine algae; type: Ctenocladaceae, *Ctenocladus*.

3. **Order Ulotrichales:** Filamentous, with a parietal chloroplast; type: Ulotrichaceae, *Ulothrix*.

4. **Order Ulvales:** Hollow cylinder or a sheet of one or two cells thick; parietal chloroplast; type: Ulvaceae, *Ulva*.

5. **Order Prasiolales:** Foliose; with stellate chloroplasts; type: Prasiolaceae, *Prasiola*.

6. **Order Microsporales:** Filamentous; cell-walls composed of H-pieces; type: Microsporaceae, *Microspora*.

7. **Order Chaetophorales:** Simple or branched filaments, heterotrichous; with plasmodesmata; type: Chaetophoraceae, *Chaetophora*.

8. **Order Coleochaetales:** Branched filaments or discoid thalli; sheathed setae present; oogamous sexual reproduction, motile cells have a covering of scales; type: Coleochaetaceae, *Coleochaete*.

ii) **Class Zygnemophyceae:** Filamentous; peculiarity in the form of cell division by cap-cell formation or sexual reproduction by conjugation.

1. **Order Oedogoniales:** Cell division by cap-cell formation; sexual reproduction by oogamy; reproductive bodies stephanokontic; type: Oedogoniaceae, *Oedogonium*.

2. **Order Zygnemales:** Cell division normal, sexual reproduction by conjugation, reproductive bodies aflagellated; type: Zygnemaceae, *Zygnema*.

iii) **Class Siphonocladophyceae:** Coenocytic or siphonaceous; filamentous or thalloid.

1. **Order Cladophorales:** Chloroplast reticulate; reproductive organs opening by fissures or simple pores; type: Cladophoraceae, *Cladophora*.

2. **Order Acrosiphonales:** Chloroplast parietal and perforate; reproductive organs opening by operculate pores; type: Acrosiphonaceae, *Acrosiphonia*.

3. **Order Sphaeropleales:** Protoplasm segregated into bands by vacuoles; type: Sphaeropleaceae, *Sphaeroplea*.

4. **Order Siphonocladales:** Siphonaceous thalli with segregative cell division; type: Siphonocladaceae, *Siphonocladus*.

5. **Order Dasycladales:** Thalli with radial symmetry composed of an erect axis bearing branches;

gametes formed in operculate cysts; type: Dasycladaceae, *Dasycladus*.

6. **Order Derbesiales:** Stephanokontic zoospores; no amyloplasts; type: Derbesiaceae, *Derbesia*.

7. **Order Codiales:** Plastids of one type only (chloroplasts); type: Codiaceae, *Codium*.

8. **Order Caulerpales:** Plastids of two types (chloroplasts and leucoplasts); type: Caulerpaceae, *Caulerpa*.

9. **Order Dichotomosiphonales:** Oogamous sexual reproduction; type: Dichotomosiphonaceae, *Dichotomosiphon*.

**II. Phylum charophyta (stonewort algae):** Pigmentation: chlorophyll a and b; flagellation: two somewhat unequal, sub-terminal, whiplash flagella; storage product: starch; cell-wall constituent cellulose and heavy calcification; no eyespot; reproduction: only oogamy, no zoospores; plant body with precise segmentation into nodes and internodes.

i) **Class Charophyceae:** Same as above.

1. **Order Charales:** Same as above; type: Characeae, *Chara*.

**III. Phylum vaucheriophyta (yellow-green algae):** Pigmentation: chlorophyll a and c<sub>1</sub>, no fucoxanthin; flagellation: two heterokontic flagella; storage product: mannitol, glucose and lipids; cell-wall constituent: cellulose, glucuronic acid; filamentous or thalloid, multicellular or coenocytic, siphonaceous thallus.

i) **Class Vaucheriophyceae:** Same as above.

1. **Order Tribonematales:** Filamentous organisms, not coenocytic; type: Tribonemataceae, *Tribonema*.

2. **Order Botrydiales:** Globose multinucleate thallus with colourless rhizoids; type: Botrydiaceae, *Botrydium*.

3. **Order Vaucheriales:** Multi-nucleate, coenocytic filaments; type: Vaucheriaceae, *Vaucheria*.

**IV. Phylum phaeophyta (brown algae):** Pigmentation: chlorophyll a, c<sub>1</sub> and c<sub>2</sub>, fucoxanthin; flagella: two lateral, anterior tinsel and posterior whiplash flagella; storage product: chrysolaminarin and D-mannitol found in vesicles in cytoplasm; cell-wall

constituent: cellulose, alginic acid and fucoidin; unilocular and plurilocular sporangia.

i) **Class Dictyophyceae:** Isomorphic alternation of generation.

1. **Order Sarcinochrysidales:** Multi-cellular thalli producing biflagellate motile cells; anterior flagellum with tubular hairs, posterior one whiplash; type: Sarcinochrysidaceae, *Sarcinochrysis*.

2. **Order Ectocarpales:** Filamentous thalli, monostromatic; intercalary growth; type: Ectocarpaceae, *Ectocarpus*.

3. **Order Ralfsiales:** Pseudoparenchymatous thalli; intercalary growth; type: Ralfsiaceae, *Ralfsia*.

4. **Order Sphacelariales:** Filamentous, multi-stromatic, apical growth; type: Sphacelariaceae, *Sphacelaria*.

5. **Order Cutleriales:** Parenchymatous; growth by trichothallic, intercalary or marginal meristem; type: Cutleriaceae, *Cutleria*.

6. **Order Tilopteridales:** Filamentous; sexual reproduction unknown; type: Tilopteridaceae, *Tilopteris*.

7. **Order Dictyotales:** Parenchymatous; sexual reproduction oogamous; type: Dictyotaceae, *Dictyota*.

ii) **Class Laminariophyceae:** Heteromorphic alternation of generation.

1. **Order Chordariales:** Filamentous, often crustose with fused cells at base and differentiated into central medulla and outer photosynthetic cortex; type: Chordariaceae, *Chordaria*.

2. **Order Sporochneales:** Thalli thread like; growth by intercalary row of dome-shaped cells covered by the base of hairs; type: Sporochneaceae, *Sporochneus*.

3. **Order Desmarestiales:** Terete or flat, pinnately branched; attached by discoid holdfast; type: Desmarestiaceae, *Desmarestia*.

4. **Order Dictyosiphonales:** Thallus solid, tubular and branched, type: Dictyosiphonaceae, *Dictyosiphon*.

5. **Order Scytosiphonales:** Thallus hollow and globular or flat and foliose; type: Scytosiphonaceae, *Scytosiphon*.

6. **Order Laminariales (kelps):** Thallus differentiated into holdfast, stipe and lamina; type: Laminariaceae, *Laminaria*.

iii) **Class Fucophyceae:** No alternation of generation, diplontic life-cycle.

1. **Order Durvilleales:** Thallus with diffuse growth; type: Durvilleaceae, *Durvillea*.

2. **Order Fucales:** Thalli with apical growth; type: Fucaeae, *Fucus*.

V. **Phylum rhodophyta (red algae):** Pigmentation: chlorophyll a and d, zeaxanthin, phycobiliproteins; flagellation: no flagella; storage product: floridean starch, floridoside and isofloridoside; cell-wall constituent: cellulose, agar-agar and carrageenan.

i) **Class Bangiophyceae:** Pit-connections may or may not be present; life cycle simple, carposporophyte not always developed, no auxiliary cell.

1. **Order Rhodochaetales:** Filamentous algae with pit-connections; gametes formed singly by mother cell; type: Rhodochaetaceae, *Rhodochaete*.

2. **Order Acrochaetales:** Algae with a uniseriate filamentous gametophyte and tetrasporophyte (if both are present), the apical cell cutting off the daughter cells by a transverse wall; type: Acrochaetiaceae, *Acrochaetium*.

3. **Order Erythropeltidales:** Multicellular algae without pit-connections; one monospore or one spermatium produced by division of a mother cell; type: Erythropeltidaceae, *Erythropeltis*.

4. **Order Bangiales:** Algae having a filamentous phase with pit-connections and a macroscopic phase without pit-connections, spores (other than monospores) formed by the division of a mother cell into at least four cells; mannan in cell-wall; type: Bangiaceae, *Bangia*.

ii) **Class Nemaliophyceae:** Pit-connections always present; auxiliary cell not distinguishable.

1. **Order Batrachospermales:** Uniaxial thalli, usually the gonimoblast develops from the carpogonium or hypogynous cell; type: Batrachospermaceae, *Batrachospermum*.

2. **Order Nemaliales:** Multi-axial thalli, gonimoblast develops as above; xylan in cell-wall; type: Nemaliaceae, *Nemalion*.

3. **Order Ahnfeltiales:** Thalli with pit-plugs without caps or cap membranes, heteromorphic

sexual life-history; carpogonia terminate ordinary filaments of a female sorus and fuse with unspecialized vegetative cells after fertilization; type: Ahnfeltiaceae, *Ahnfeltia*.

4. **Order Gelidiales:** Uniaxial thalli with the carpogonial branch consisting of a single cell, the carpogonium; type: Gelidiaceae, *Gelidium*.

iii) **Class Ceramiophyceae:** Auxiliary cells well developed, formed before or after fertilization.

1. **Order Gracilariales:** Carpogonial filaments two-celled and inconspicuous, after fertilization carpogonium fuses with one of the nutritive cells, acting as auxiliary cell; type: Gracilariaceae, *Gracilaria*.

2. **Order Bonnemaisoniales:** Cystocarps surrounded by definite pericarp; life-history usually comprises dissimilar phases; type: Bonnemaisoniaceae, *Bonnemaisonia*.

3. **Order Corallinales:** Thalli calcified, crustose or erect with segmented organization; reproductive structures produced in conceptacles; type: Corallinaceae, *Corallina*.

4. **Order Gigartinales:** Auxiliary cell forms prior to fertilization and receives the zygote or zygote-derived nuclei from the carpogonium via an external connection; type: Gigartinaceae, *Gigartina*.

5. **Order Cryptonemiales:** Generative auxiliary cell occurring in an accessory, non-vegetative filament, either borne on the supporting cell of the carpogonial branch or remote from the carpogonial branch; type: Cryptonemiaceae, *Cryptonemia*.

6. **Order Plocamiales:** Peculiar nucleotide sequences in the small-subunit ribosomal RNA gene; anatomical complications; type: Plocamiaceae, *Plocamium*.

7. **Order Rhodymeniales:** Generative auxiliary cell the terminal cell of a two-celled filament borne on the supporting cell of the carpogonial branch; type: Rhodymeniaceae, *Rhodymenia*.

8. **Order Palmariales:** Zygote develops directly into tetrasporophyte; there is no carposporophyte, female gametophyte is small, male gametophyte and tetrasporophyte are large with the same morphology; type: Palmariaceae, *Palmaria*.

9. **Order Ceramiales:** Auxiliary cell cut off after fertilization and borne on the supporting cell of the four-celled carpogonial filament; xylan in cell-wall; type: Ceramiaceae, *Ceramium*.

## Discussion

This classification is based on the views of dividing the living world in five kingdoms<sup>1</sup>. It takes a good advantage of the modern classifications, which are based on ultrastructural characteristics of algae<sup>2</sup>. Three new phyla, 10 new classes and four new orders have been created<sup>3</sup>. As far as possible, typified names are preferred here to descriptive names. Overall algae have been divided into 19 phyla, their diagnostic features and other characteristics have been summarised in Table 1.

In all the previous classifications, the division Cyanophyta was shown to contain a single class the Cyanophyceae, for the first time an effort has been made to divide this large procaryotic phylum into two classes. The term Cyanophyta is preferred here to Cyanobacteria because these organisms are less bacteria and more algae. Their resemblance with bacteria is only due to parallelism but their similarity with algae is due to kinship. They are related to the Chlorophyta through transitional stages like Prochlorophyta, Glaucophyta, Micromonadophyceae and Volvocophyceae. This indicates a direct line of evolution. All the unicellular and colonial algae have been separated from the Chlorophyta and placed under a new phylum Volvocophyta, along with certain other flagellates and desmids.

Six orders are recognized in the Euglenophyta<sup>4</sup>, but only the most common three are considered here<sup>5</sup>. Class Dictyochophyceae has been separated from the Chrysophyceae due to the presence of tentacles or rhizopodia on basically amoeboid vegetative cells<sup>6,7</sup>. The Pelagophyceae has been distinguished on the basis of nuclear data<sup>8</sup>. The name Dinophyta is preferred to Pyrrophyta due to the common use of several terms like dinoflagellate, dinocaryotic condition, dinoxanthin, diadinoxanthin etc. as well as due to many ordinal taxa like Dinophysiales, Dinocapsales, Dinococcales, Dinotrichales etc. included in this phylum. The name Prymnesiophyta is preferred to Haptophyta or Coccolithophyta, due to a typified name<sup>9</sup>. No doubt, names of all the phyla are not typified.

The order Sarcinochrysidales has been removed from the Chrysophyta and placed under Phaeophyta due to its close affinity and similarity with brown algae, especially in flagellation. Contrary to the view of dividing the division Bacillariophyta in two classes Centrobacillariophyceae and Penatibacillariophyceae<sup>10</sup>, only one class Bacillariophyceae is distinguished here.

TABLE 1  
Diagnostic Characters of the *Algal phyla*

| Algal phyla     | Chlor. Carot.                              | Xanthophylls. Phycobilins                                       | Thyl/ band | Memb. of CER | Flagellation                  | Storage product            | Cell-wall constituents                    |
|-----------------|--|---|------------|--------------|-------------------------------|----------------------------|---|
| Cyanophyta      | a<br>β                                     | Echinenone, myxoxanthophyll<br>C-Phycocyanin, C-phycoerythrin   | 1          | —            | —                             | Glycogen, cyanophycin<br>— | Peptidoglycan, muramic acid               |
| Prochlorophyta  | a, b<br>β                                  | Zeaxanthin, cryptoxanthin<br>—                                  | 2-6        | —            | —                             | Monogalactolipid<br>—      | Peptidoglycan, muramic acid               |
| Glaucophyta     | a<br>β                                     | Zeaxanthin, aphanizophyll<br>C-Phycocyanin, C-phycoerythrin     | 1          | —            | 2, Subapical,<br>anisokontic  | Starch<br>O                | Carbohydrates, proteins,<br>phospholipids |
| Volvocophyta    | a, b<br>α, β                               | Lutein, neoxanthin  | 2-5        | —            | 2,4, Apical,<br>isokontic     | Starch<br>1                | Glycoproteins, acidic<br>polysaccharides  |
| Euglenophyta    | a, b<br>β, γ                               | Diadinoxanthin, neoxanthin                                      | 3          | 1            | 1,2, Apical,<br>heterokontic  | Paramylon<br>O             | Proteins, lipids, carbohydrates           |
| Dinophyta       | a, c <sub>2</sub><br>β                     | Peridinin, neoperidinin   | 3          | 1            | 2, Lateral,<br>heterokontic   | Starch, rarely oil<br>O    | Cellulose                                 |
| Cryptophyta     | a, c <sub>2</sub><br>α, β                  | Diatoxanthin, monadoxanthin<br>3 Phycocyanins, 3 phycoerythrins | 2          | 2            | 2, Apical or<br>lateral       | Starch<br>B                | Polysaccharide, periplast                 |
| Chrysophyta     | a, c <sub>1</sub> , c <sub>2</sub><br>β    | Fucoxanthin, echinenone   | 3          | 2            | 2, Subapical<br>heterokontic  | Chrysolaminarin<br>O       | Silica scales                             |
| Prymnesiophyta  | a, c <sub>1</sub> , c <sub>2</sub><br>β    | Fucoxanthin, echinenone   | 3          | 2            | 2, Isokontic,<br>haptoneма    | Chrysolaminarin<br>O       | Calcites, rarely aragonite                |
| Bacillariophyta | a, c <sub>1</sub> , c <sub>2</sub><br>α, β | Diatoxanthin, diadinoxanthin                                    | 3          | 2            | 1, -, Posterior,<br>tinsel    | Chrysolaminarin, oil<br>O  | Silica, bipartite, sculptured             |
| Xanthophyta     | a<br>β                                     | Heteroxanthin, diadinoxanthin                                   | 3          | 2            | 2, Subapical,<br>heterokontic | Glucan, lipids<br>O        | Cellulose, glucuronic acid                |

Contd.....

| Algal phyla      | Chlor.<br>Carot.                        | Xanthophylls<br>Phycobilins                                    | Thyl./<br>band | Memb.<br>of CER | Flagellation                    | Storage<br>product                       | Cell-wall<br>constituents         |
|------------------|---|--|----------------|-----------------|---------------------------------|--|-----------------------------------|
| Eustigmatophyta  | a<br>b                                  | Violaxanthin, vaucheriaxanthin                                 | 3              | 2               | 1, 2, Apical,<br>heterokontic   | Oil<br>O                                 | Polysaccharide                    |
| Raphidophyta     | a, c <sub>1</sub><br>β                  | Fucoxanthin, antheraxanthin                                    | 3              | 2               | 2, Heterokontic,<br>projectiles | Fat particles<br>O                       | Gelatin                           |
| Porphyridiophyta | a, d<br>α, β                            | Antheraxanthin, neoxanthin<br>B-Phycoerythrin, b-phycoerythrin | 1              | —               | —                               | Floridean starch,<br>isofloridoside<br>1 | Polysaccharide, mucilage          |
| Chlorophyta      | a, b<br>α, β                            | Lutein, siphonoxanthin<br>—                                    | 3-6            | —               | 2,4, Apical,<br>isokontic       | Starch, frutosan<br>1                    | Cellulose, mannan, xylan          |
| Charophyta       | a, b<br>α, β                            | Neoxanthin, zeaxanthin   | 4-6            | —               | 2, Subapical<br>anisokontic     | Starch<br>O                              | Cellulose, pectin, calcite        |
| Vaucheriophyta   | a, c<br>β                               | Vaucheriaxanthin, heteroxanthin                                | 3              | 2               | 2, Apical,<br>heterokontic      | Mannitol, glucose, lipids<br>1           | Cellulose, glucose, uronic acids  |
| Phaeophyta       | a, c <sub>1</sub> , c <sub>2</sub><br>β | Fucoxanthin, violaxanthin                                      | 3              | 2               | 2, Lateral,<br>heterokontic     | Laminarin, mannitol<br>O                 | Cellulose, alginic acid, fucoidin |
| Rhodophyta       | a, d<br>α, β                            | Zeaxanthin, cryptoxanthin<br>R-Phycocyanin, R-phycoerythrin    | 1              | —               | —                               | Floridean starch,<br>floridoside<br>O    | Cellulose, galactans, xylan       |

14

- Carot. = carotenes  
 Chlor. = chlorophylls  
 Memb. = membranes  
 Thyl. = thylakoids  
 B = between chloroplast envelope and CER  
 I = inside chloroplast  
 O = outside chloroplast (place where storage product is found)  
 — = absent.

Instead of distributing diatoms in nine orders or several suborders<sup>11,12</sup>, only two orders are distinguished in the present treatment. The names Biddulphiales and Bacillariales are preferred to Centrales and Pennales, only as being typified. The orders Tribonematales, Botrydiales and Vaucheriales being filamentous or thalloid, multicellular or coenocytic, have been separated from the Xanthophyta and placed under a new phylum Vaucheriophyta because only the unicellular and colonial genera are placed under Xanthophyta. The name Raphidophyta is preferred to Chloromonadophyta, being more appropriate.

Among Chlorophyta, the Oedogoniales and Zygnemales have been placed together under the class Zygnemophyceae due to their very peculiar characters. Several *Bryopsis* species were found to produce stephanokontic zoospores and serve as gametophyte of a *Derbesia*<sup>13, 14, 15, 16</sup>, therefore, it appears more plausible to place *Bryopsis* in the Derbesiaceae instead of its own family Bryopsidaceae. As a result, all the higher typified taxa lose their existence. Therefore, the name Bryopsidophyceae has been replaced by a new name Siphonocladophyceae. It is a typified name but simultaneously describes the siphonaceous and cladophoraceous characters of this class, hence appears to be a much better name. Except the inclusion of Sarcinochrysidales, no drastic change is brought about in classifying the Phaeophyta.

Porphyridiales has been separated from the Rhodophyta due to unicellular individuals or loosely arranged cells within a mucilaginous thallus, and placed under a new phylum Porphyridiophyta. Contrary to all the previous classifications, Rhodophyta is divided on the basis of auxiliary cells in three classes, among which Nemaliophyceae and Ceramiophyceae are new ones. The name Batrachospermales is preferred to Lemaneales due to common use of the genus *Batrachospermum*. *Ahnfeltia* is removed from the Gigartinales and placed under its own family and order<sup>17</sup>. All the calcareous algae of the Gigartinales have been separately placed under Corallinales<sup>18</sup>. On the basis of reproductive development the Gracilariaceae is also removed from the Gigartinales and placed under its own order<sup>19</sup>. The family Plocamiaceae has been elevated to an order due to characteristic nucleotide sequences in the small sub-unit ribosomal RNA gene along with its anatomical features<sup>20</sup>.

Gene sequencing has been the most active field of algal taxonomy in the last decade of the past

millennium. It has provided new information on the relationships of various algal taxa. In this connection, further information might open new vistas in the realm of phycology, especially the classification of algae.

#### Acknowledgement

This work was financially supported by a research grant of Oceanic Naval Research, USA (Res. Proj. No. NP-3), which is gratefully acknowledged.

#### REFERENCES

- Whittaker, R. and Margulis, L., (1978). Protist classification of the kingdoms of organisms, *BioSystems*, 10, pp. 3-18.
- Lee, R.E., (1999). *Phycology*, 3rd ed., Camb. Univ. Press, Cambridge, 614 pp.
- Shameel, M., (2001). An approach to the classification of algae in the new millennium, *Pak. J. Mar. Biol.*, 7, pp. 233-250.
- Leedale, G.F., (1967). *Euglenoid Flagellates* Prentice-Hall, Englewood Cliffs.
- Montegut-Felkner, A.E. and Triemer, R.E., (1977). Phylogenetic relationships in selected euglenoid genera based on morphological and molecular data, *J. Phycol.*, 33, pp. 512-519.
- Moestrup, O., (1995). Current status of Chrysophyta 'splinter groups': synurophytes, pedinellids, silicoflagellates, *In: Sandgren, C.D., Smol, J.R. and Kristiansen, J., eds., Chrysophyte Algae*, Camb. Univ. Press, Cambridge, p. 75-91.
- Preisig, H.R., (1995). A modern concept of chrysophyte classification, *In: Sandgren, C.D., Smol, J.R. and Kristiansen, J., eds., Chrysophyte Algae*, Camb. Univ. Press, Cambridge, pp. 46-74.
- Saunders, G.W., Potter, D. and Andersen, R.A., (1997). Phylogenetic affinities of the Sarcinochrysidales and Chrysomeridales (Heterokonta) based on analysis of molecular and combined data, *J. Phycol.*, 33, pp: 310-318.
- Hibberd, D.J., (1976). The ultrastructure and taxonomy of the Chrysophyceae and Prymnesiophyceae. (Haptophyceae): A survey with some new observations on the ultrastructure of the Chrysophyceae, *Bot. J. Linn. Soc.*, 72, pp. 55-80.
- Silva, P.C., (1962). Classification of algae. *In: Lewin R.A., ed., Physiology and Biochemistry of Algae*, Acad Press, New York, pp. 827-837.
- Patrick, R. and Reimer, C.W., (1966). *The Diatoms of the United States Exclusive of Alaska and Hawaii*, Vol. 1, *Fragilariaceae, Eunotiaceae, Achnanthaceae, Naviculaceae*, Monogr. Acad. Natural Sci., Philadelphia, 688 pp.
- Patrick, R. and Reimer, C.W., (1975). *The Diatoms of the United States Exclusive of Alaska and Hawaii*, Vol. 2, Part 1, *Entomoneidaceae, Cymbellaceae, Gomphonemaceae, Epithemiaceae*, Monogr. Acad. Natural Sci., Philadelphia, 213 pp.

13. Rietema, H., (1969). A new type of life-history in *Bryopsis*, *Acta Bot. Neerl.*, 18, pp. 615-619.
14. Rietema, H., (1970). Life-histories of *Bryopsis plumosa* (Chlorophyceae, Caulerpales) from European coasts, *Acta Bot. Neerl.*, 19, pp. 859-866.
15. Rietema, H., (1971). Life-history studies in the genus *Bryopsis* (Chlorophyceae), III, The life-history of *Bryopsis monoica* Funk, *Acta Bot. Neerl.*, 20, pp. 205-210.
16. Rietema, H., (1971). Life-history studies in the genus *Bryopsis* (Chlorophyceae), IV, Life-histories in *Bryopsis hypnoides* Lamx. from different points along the European coasts, *Acta Bot. Neerl.*, 20, pp. 291-298.
17. Maggs, C.A. and Pueschel, C.M., (1989). Morphology and development of *Ahnfeltia plicata* (Rhodophyta): proposal of Ahnfeltiales Aord. nov., *J. Phycol.*, 25, pp. 333-351.
18. Silva, P.C. and Johansen, H.W., (1986). A reappraisal of the order Corallinales (Rhodophyceae), *Br. Phycol. J.*, 21, pp. 245-254.
19. Fredricq, S. and Hommersand, M.H., (1989). Proposal of the Gracilariales ord. nov. (Rhodophyta), *J. Phycol.*, 25, pp. 213-227.
20. Saunders, G.W. and Kraft, G.T., (1994). Small sub-unit rRNA gene sequences from representatives of selected families of the Gigartinales and Rhodymeniales (Rhodophyta), I, Evidence for the Plocamiales ord. nov., *Cand. J. Bot.*, 72, pp. 1250-1263.