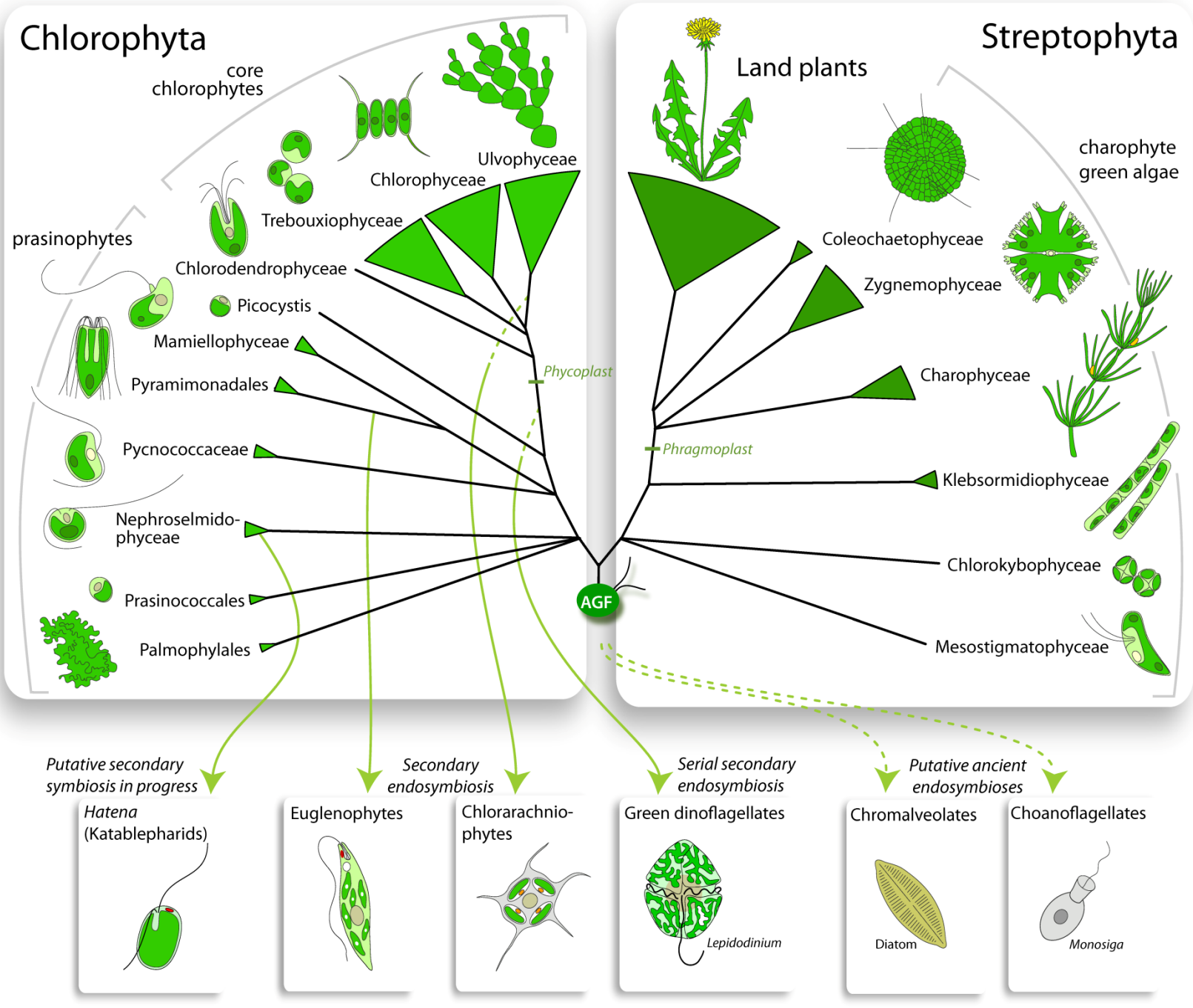
Kingdom: Archaeplastida

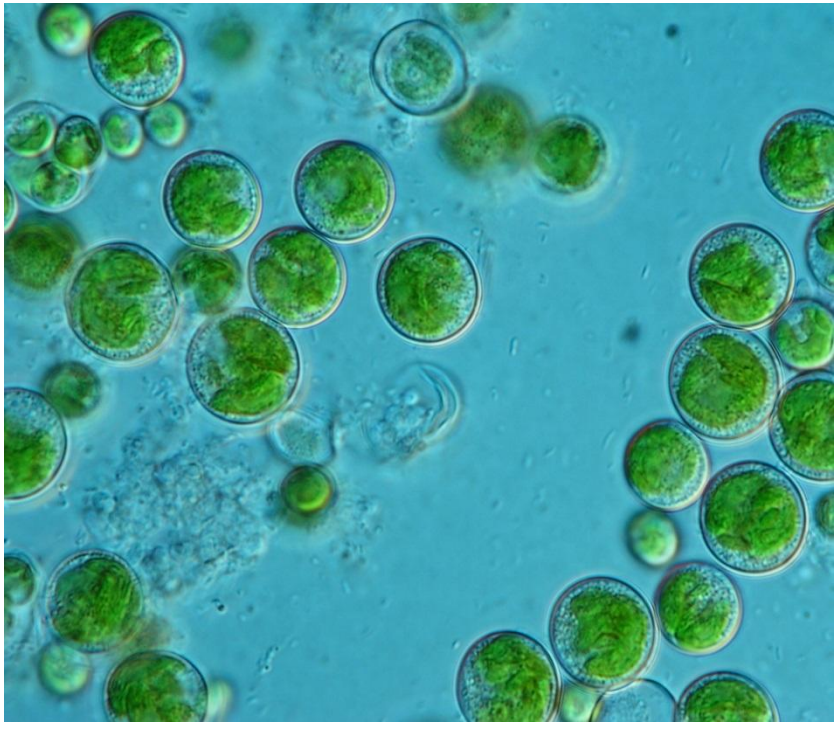
Order: Chlorophyta

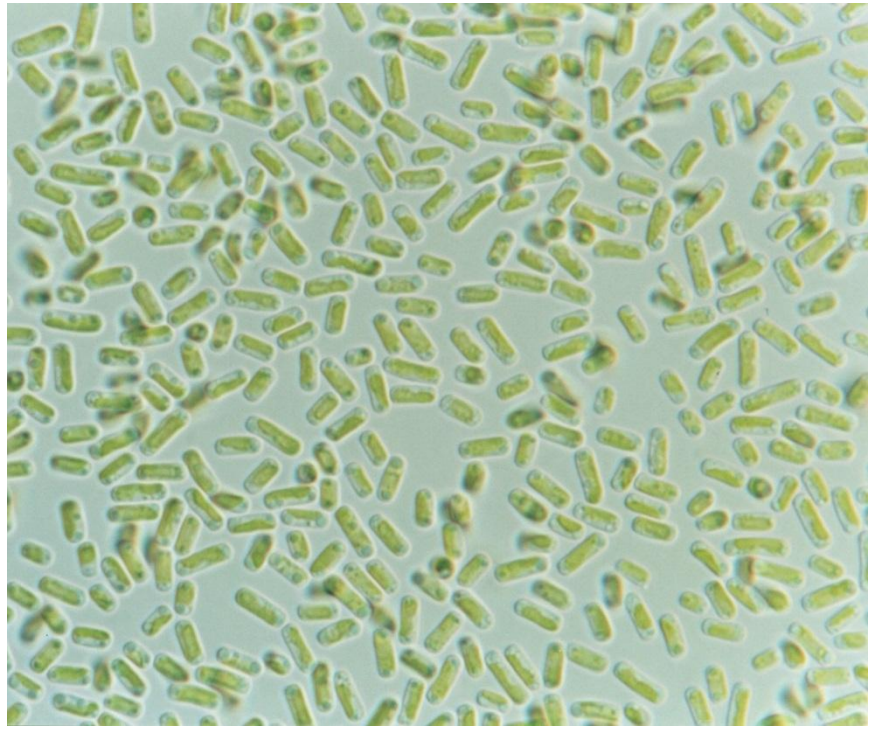
Class: Trebouxiophyceae


Chlorophyta
core chlorophytes
Ulvophyceae
Chlorophyceae
Trebouxiophyceae
prasinophytes
Chlorodendrophyceae
Picocystis
Mamiellophyceae
Pyramimonadales
Pycnococcaceae
Nephroselmido-phyceae
Prasinococcales
Palmophylales
Phycoplast
Streptophyta
Land plants
charophyte green algae
Coleochaetophyceae
Zygnemophyceae
Charophyceae
Phragmoplast
Klebsormidiophyceae
Chlorokybophyceae
Mesostigmatophyceae
AGF
Putative secondary symbiosis in progress
Hatena (Katablepharids)
Secondary endosymbiosis
Euglenophytes
Chlorarachnio-phytes
Serial secondary endosymbiosis
Green dinoflagellates
Lepidodinium
Putative ancient endosymbioses
Chromalveolates
Diatom
Choanoflagellates
Monosiga

General features

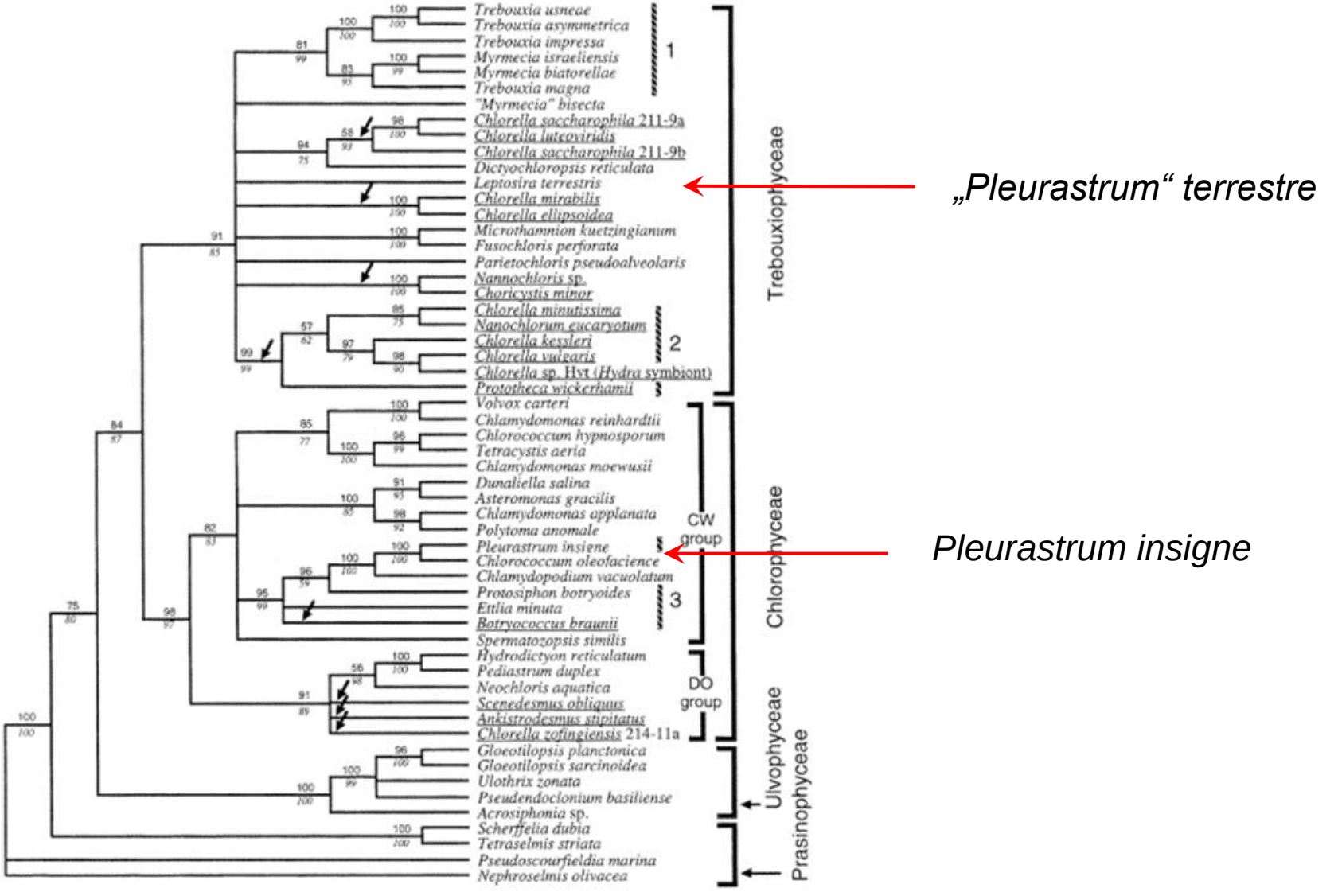
- unicellular and filamentous algae
- predominantly terrestrial, aerophytic
- a high proportion of symbiotic organisms

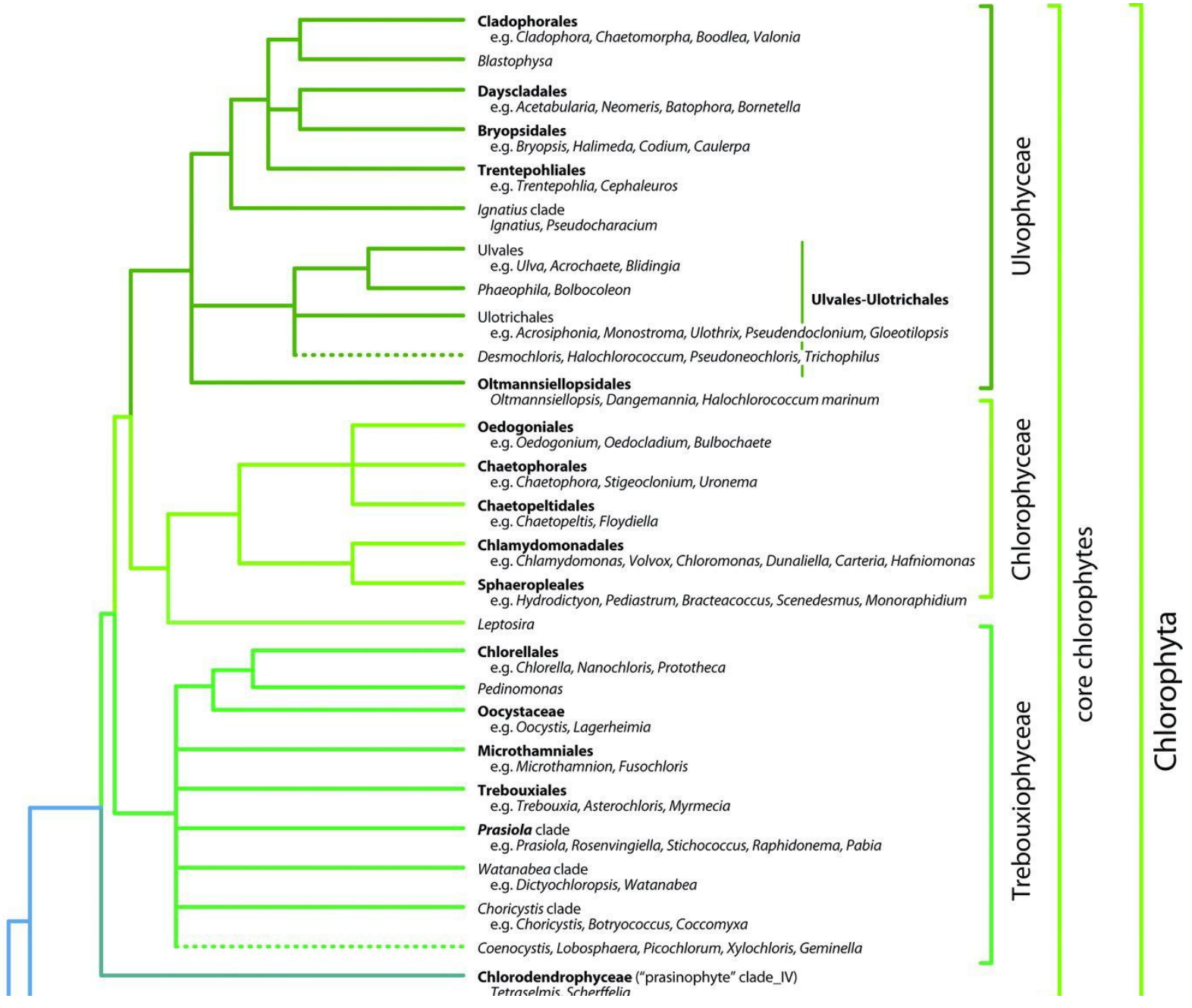




Mattox & Stewart (1984): Pleurastrophyceae (characterized by DO orientation of flagellar roots)

Friedl (1996): Trebouxiophyceae



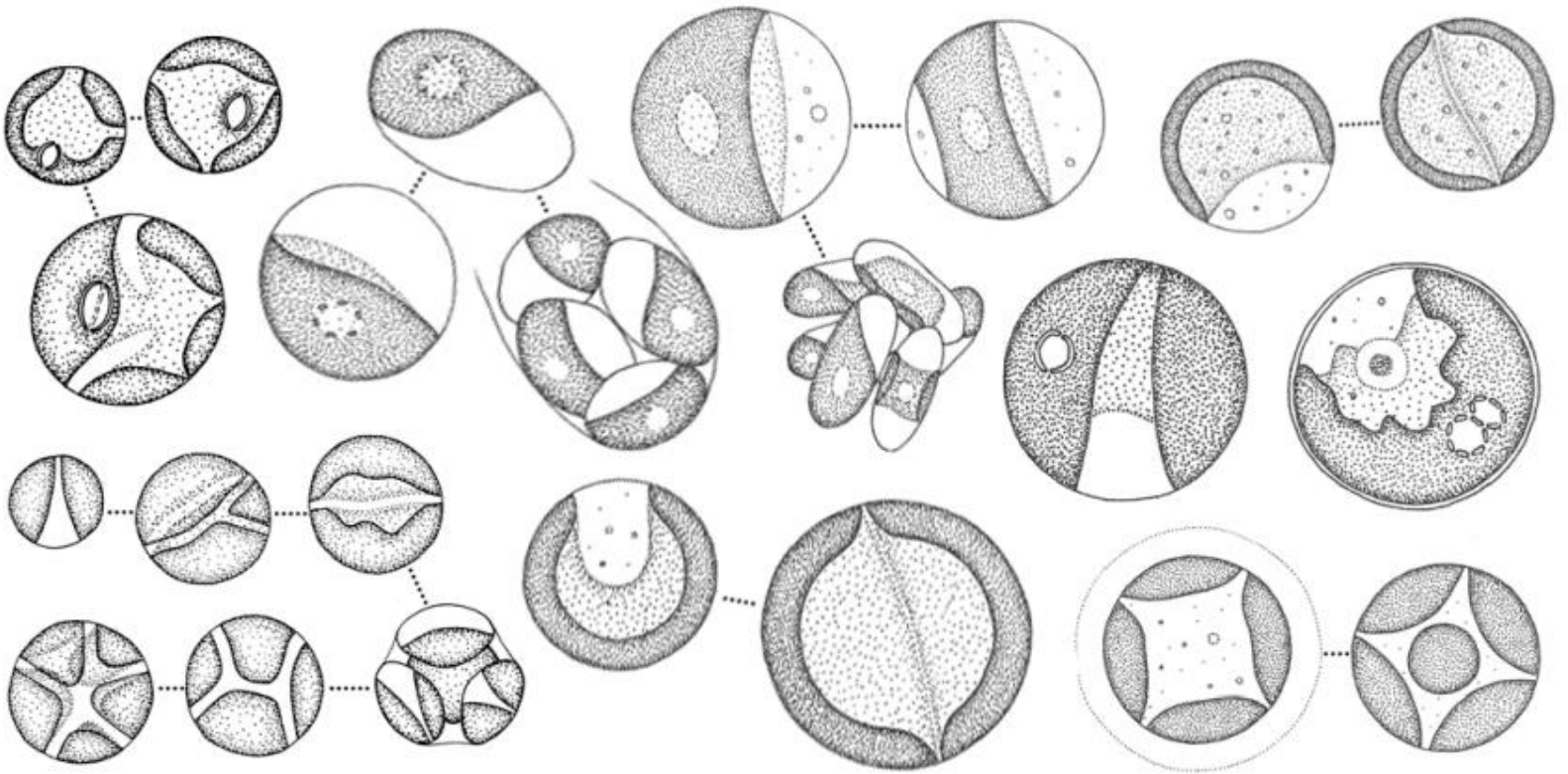

Cladophorales
e.g. Cladophora, Chaetomorpha, Boodlea, Valonia
Blastophysa
Dayscladales
e.g. Acetabularia, Neomeris, Batophora, Bornetella
Bryopsidales
e.g. Bryopsis, Halimeda, Codium, Caulerpa
Trentepohliales
e.g. Trentepohlia, Cephaleuros
Ignatius clade
Ignatius, Pseudocharacium
Ulvales
e.g. Ulva, Acrochaete, Blidingia
Phaeophila, Bolbocoleon
Ulotrichales
e.g. Acrosiphonia, Monostroma, Ulothrix, Pseudendoclonium, Gloeotilopsis
Desmochloris, Halochlorococcum, Pseudoneochloris, Trichophilus
Ulvales-Ulotrichales
Oltmannsiellopsidales
Oltmannsiellopsis, Dangemannia, Halochlorococcum marinum
Ulvophyceae
Oedogoniales
e.g. Oedogonium, Oedocladium, Bulbochaete
Chaetophorales
e.g. Chaetophora, Stigeoclonium, Uronema
Chaetopeltidales
e.g. Chaetopeltis, Floydiella
Chlamydomonadales
e.g. Chlamydomonas, Volvox, Chloromonas, Dunaliella, Carteria, Hafniomonas
Sphaeropleales
e.g. Hydrodictyon, Pediastrum, Bracteacoccus, Scenedesmus, Monoraphidium
Chlorophyceae
Leptosira
Chlorellales
e.g. Chlorella, Nanochloris, Prototheca
Pedinomonas
Oocystaceae
e.g. Oocystis, Lagerheimia
Microthamniales
e.g. Microthamnion, Fusochloris
Trebouxiales
e.g. Trebouxia, Asterochloris, Myrmecia
Prasiola clade
e.g. Prasiola, Rosenvingiella, Stichococcus, Raphidonema, Pabia
Watanabea clade
e.g. Dictyochloropsis, Watanabea
Choricystis clade
e.g. Choricystis, Botryococcus, Coccomyxa
Coenocystis, Lobosphaera, Picochlorum, Xylochloris, Geminella
Trebouxiophyceae
Chlorodendrophyceae ("prasinophyte" clade_IV)
Tetraselmis, Scherffelia
core chlorophytes
Chlorophyta

Trebouxiophyceae, *Chlorella*

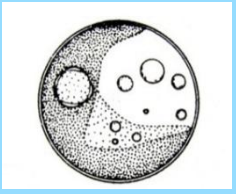
- Coccoid unicellular green algae with globular to oval cells that reproduce entirely by autospores
- Probably the most abundant and diversified group of aerophytic algae
- Beijerinck (1890):

  „... ich werde unten die Algen derart beschreiben, dass jeder dieselben leicht erkennen kann.“

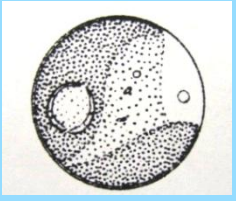
  „... now I describe this alga in such a way that everybody will simply distinguish it... “



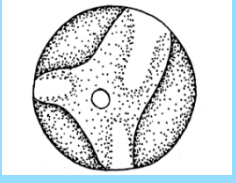
Trebouxiophyceae, *Chlorella*



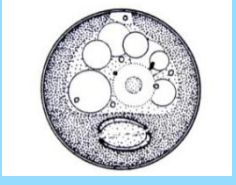
Chlorella vulgaris



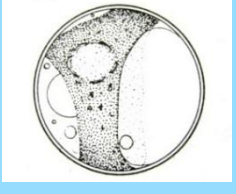
Chlorella sorokiniana



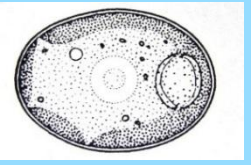
Chlorella lobophora



Chlorella kessleri

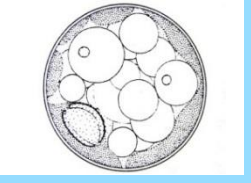


Chlorella luteoviridis

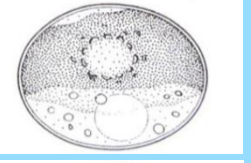


Chlorella fusca v. fusca

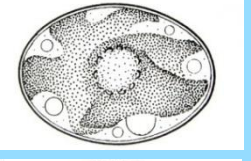
Chlorella fusca v. rubescens



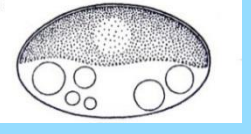
Chlorella fusca v. vacuolatus



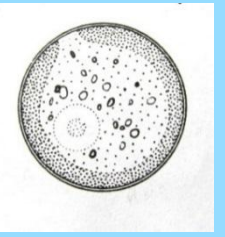
Chlorella ellipsoidea



Chlorella trebouxioides



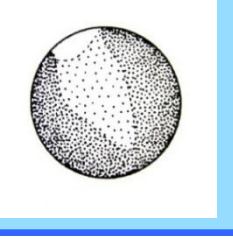
Chlorella saccharophila



Chlorella homosphaera

Chlorella zofingiensis

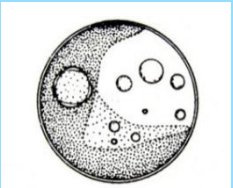
Chlorella protothecoides



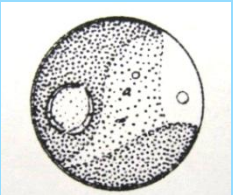
Chlorella minutissima

Trebouxiophyceae, *Chlorella*

glukosamin

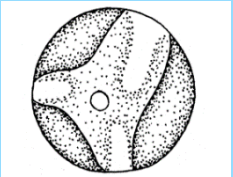


Chlorella vulgaris



Chlorella sorokiniana

(Ch. vulgaris)



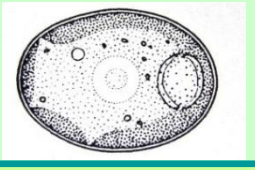
Chlorella lobophora

Parachlorella kessleri

(Ch. kessleri)

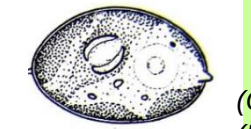
Jaagichlorella luteoviridis

(Ch. luteoviridis)



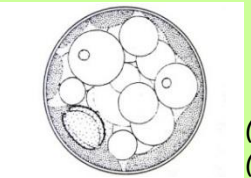
Desmodesmus abundans

(Ch. fusca, v. fusca)
(Scen. abundans)



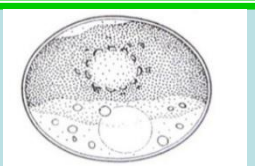
Scenedesmus rubescens

(Ch. fusca, v. rubescens)
(Halochlorella rubescens)



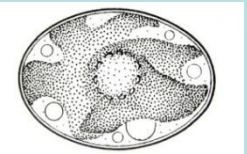
Scenedesmus vacuolatus

(Ch. fusca, v. vacuolata)
(Graesiella vacuolata)



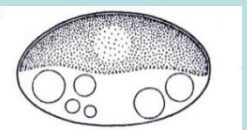
Chloroidium ellipsoideum

(Ch. ellipsoidea)



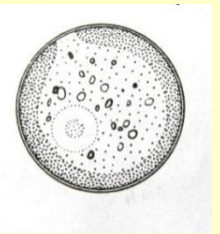
Chloroidium ellipsoideum

(Ch. trebouxioides)



Chloroidium saccharophilum

(Ch. saccharophila)

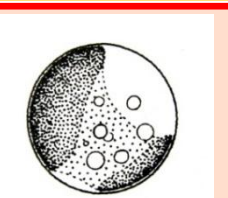


Mychonastes homosphaera

(Ch. homosphaera, Ch. minutissima)

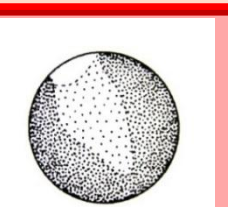
Chromochloris zofingiensis

(Ch. zofingiensis)



Auxenochlorella protothecoides

(Ch. protothecoides)

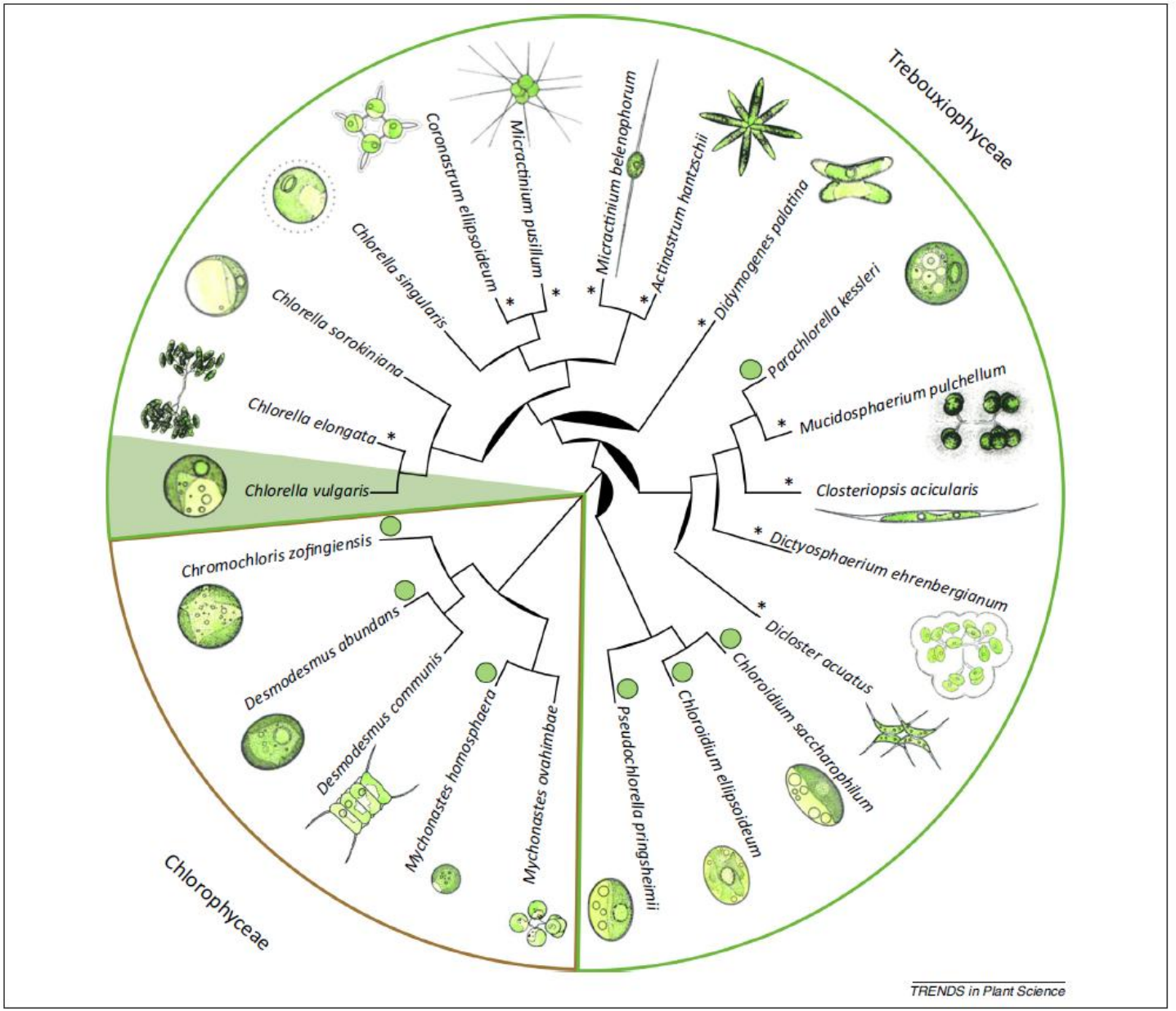


Pseudochloris wilhelmii

(“Ch. minutissima”)

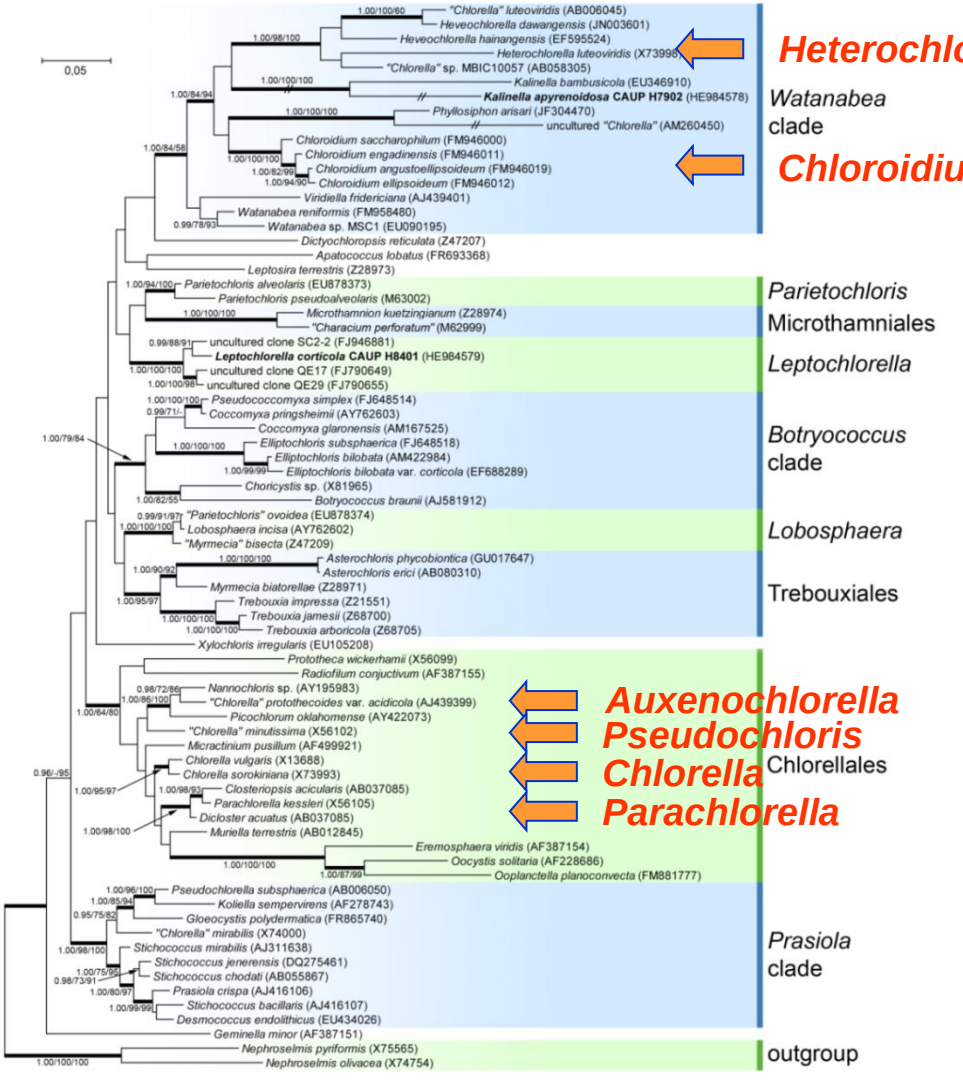
An et al. (1999), Huss et al. (1999), Krienitz et al. (2004), Darienko et al. (2010), Neustupa et al. (2009), Fučíková & Lewis (2012), Somogyi et al. (2013)

Trebouxiophyceae, *Chlorella*



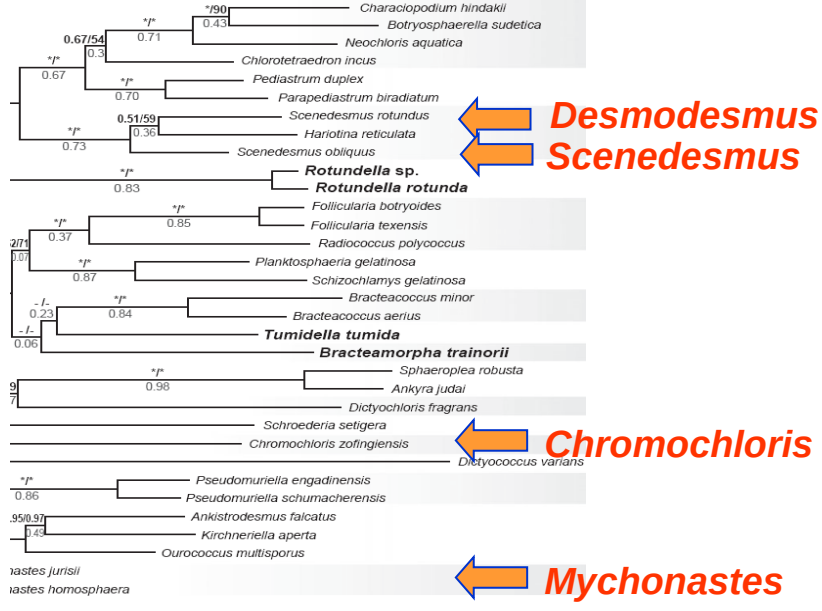
Trebouxiophyceae, *Chlorella*

Trebouxiophyceae:



- In subaerial conditions, the drought stress drives selection towards the globular forms with low surface-to-volume ratio
- Traditionally circumscribed *Chlorella* species fall into at least 10 different lineages/genera

Chlorophyceae:



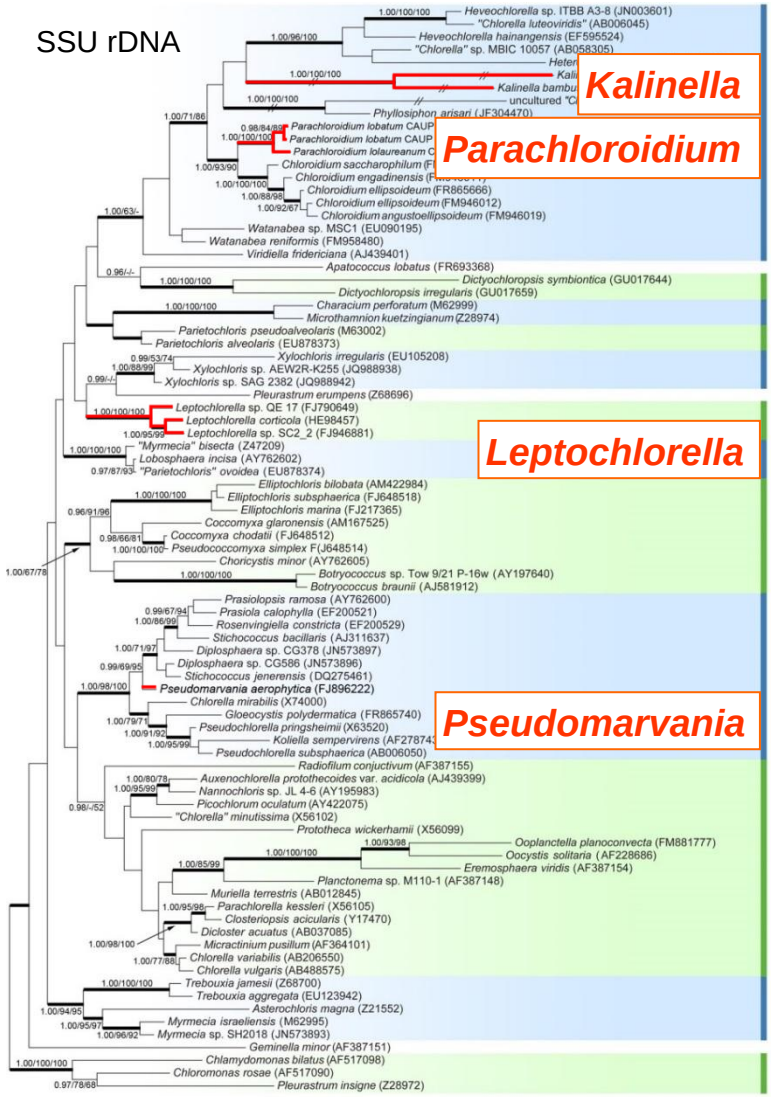
Trebouxiophyceae, *Chlorella* – cryptic genera

Chlorophyceae:

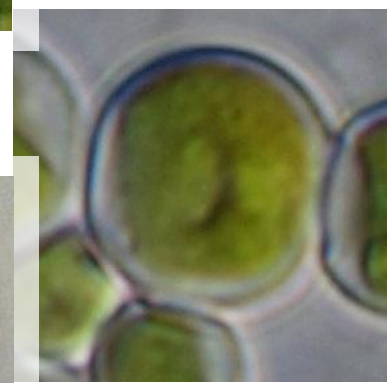
Němcová et al. (2011): *Journal of Phycology* **47**, 928-938

Trebouxiophyceae, *Chlorella* – cryptic genera

SSU rDNA



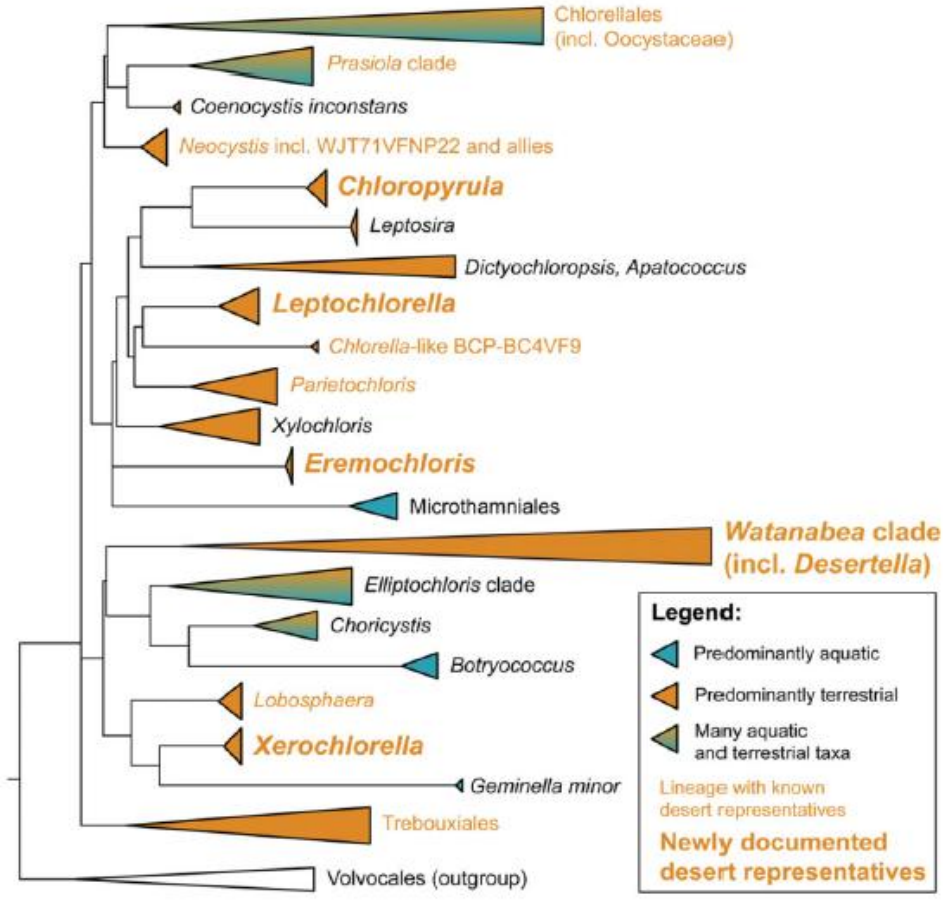
Trebouxiophyceae:

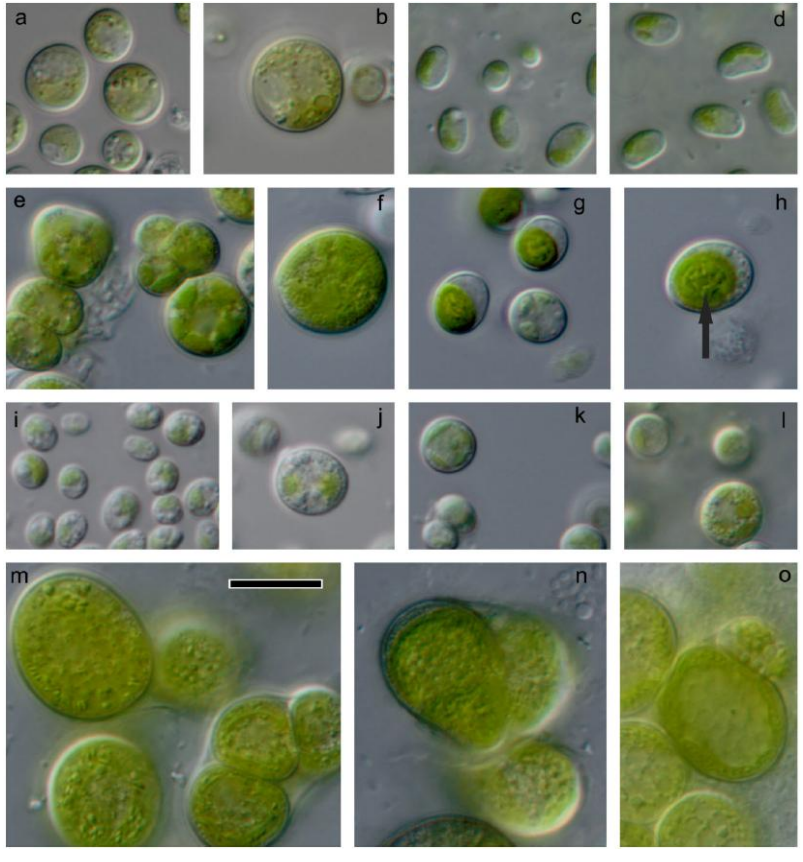


Neustupa et al. (2013): *Phycologia* **52**, 411-421; Neustupa et al. (2013): *IJSEM* **63**, 377-387 ; Neustupa et al. (2009): *Phycological Research* **57**, 159-169; Eliáš & Neustupa (2009): *Fottea* 9, 169-177

Trebouxiophyceae, cryptic genera

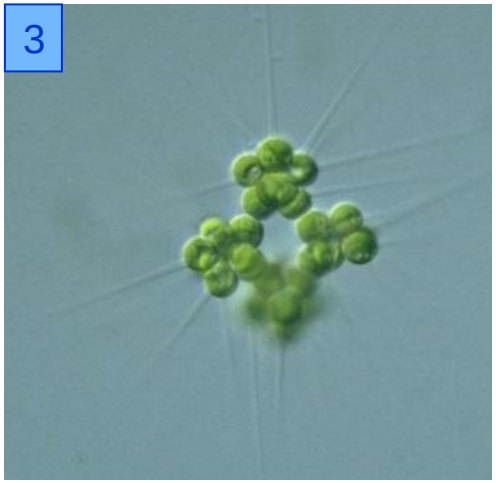
– Fučíková et al. (2014) – desert Trebouxiophyceae

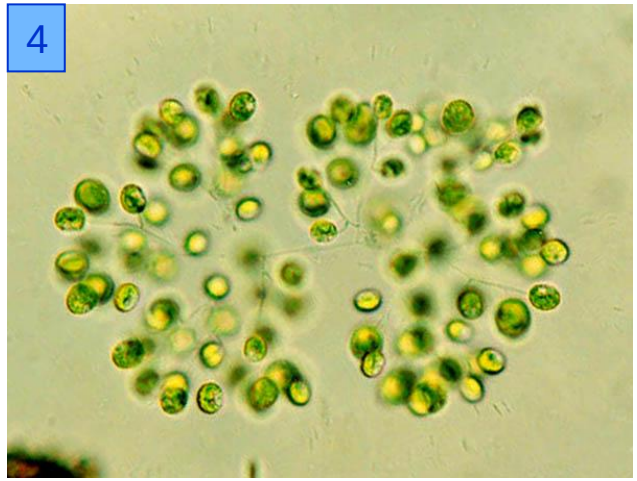


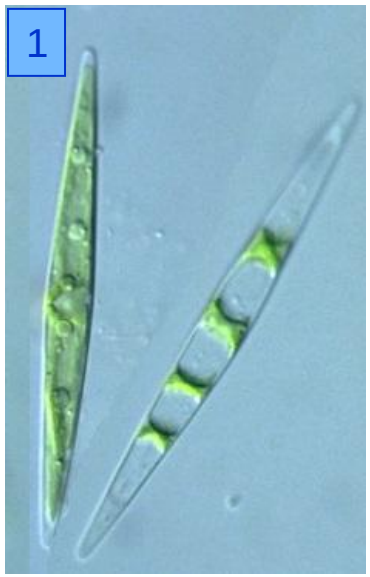


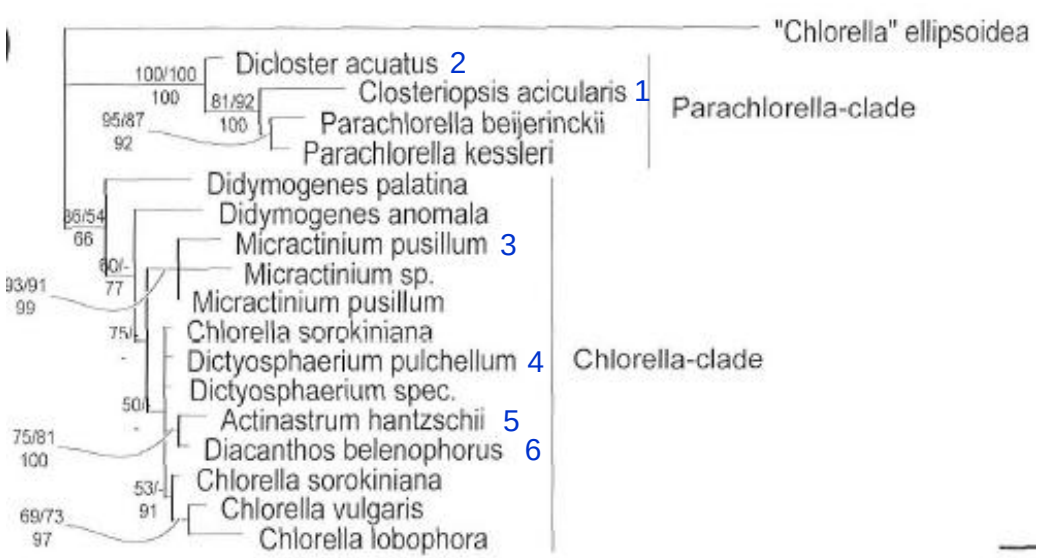
Trebouxiophyceae, Chlorellales

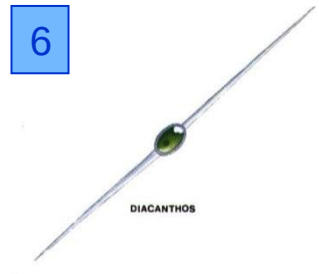
- morphologically distinct planktonic genera are close related to *Chlorella*







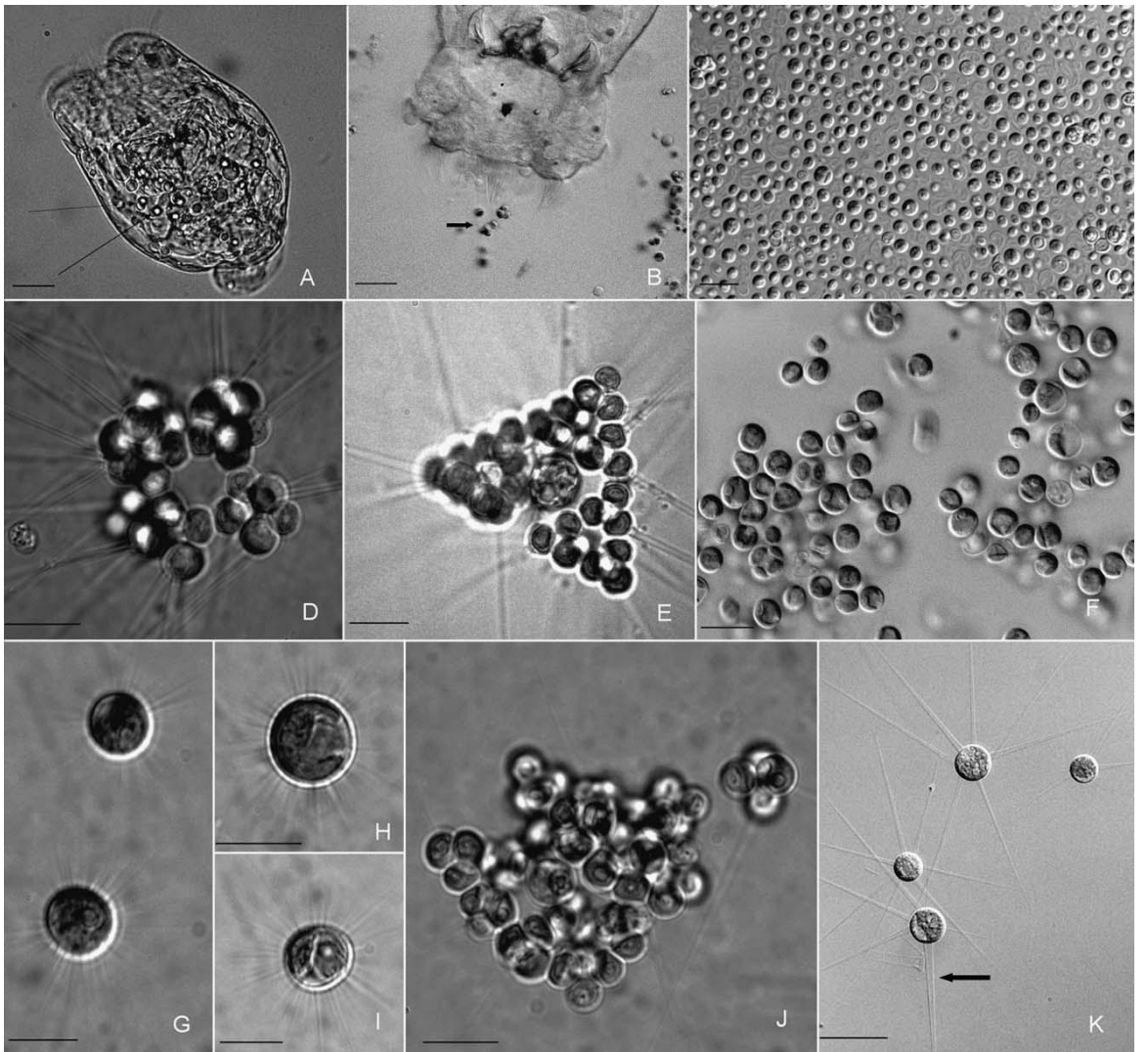


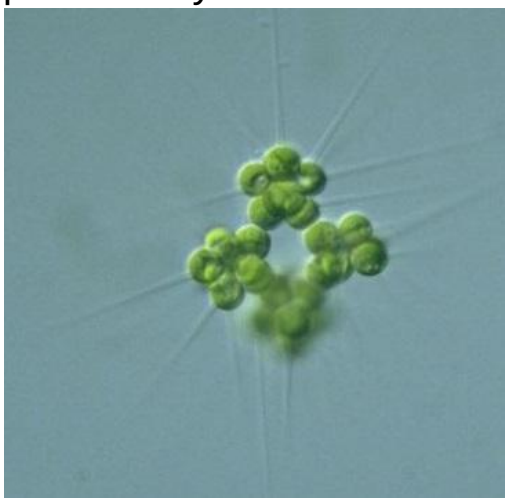


Krienitz et al. (2004): *Phycologia* **43**, 529-542

Trebouxiophyceae, Chlorellales

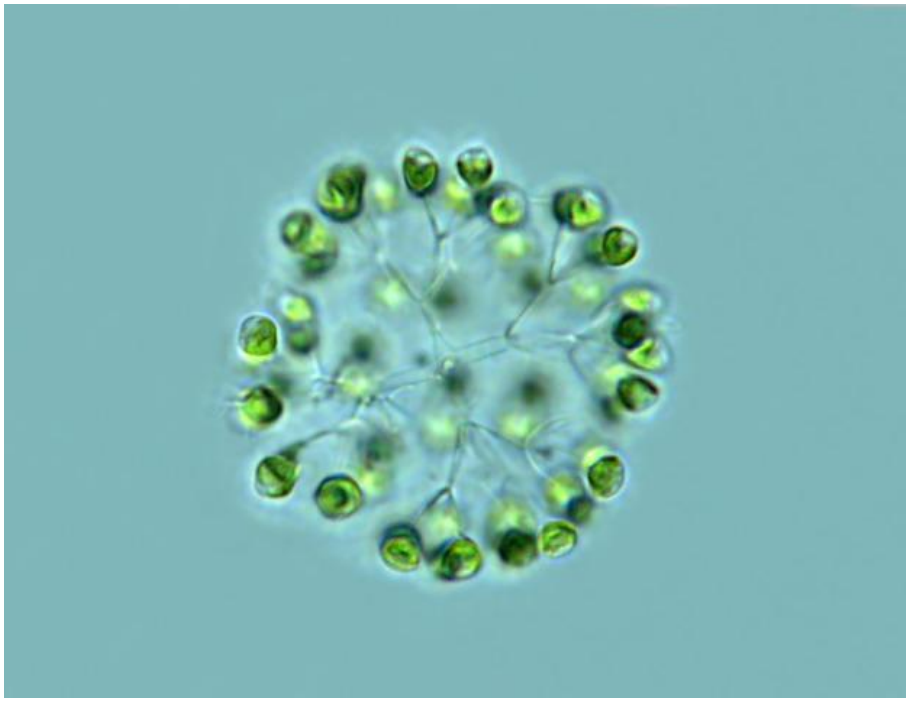
- Luo et al. (2006)
- production of spines in *Micractinium* as a result of predation pressure by *Brachionus*

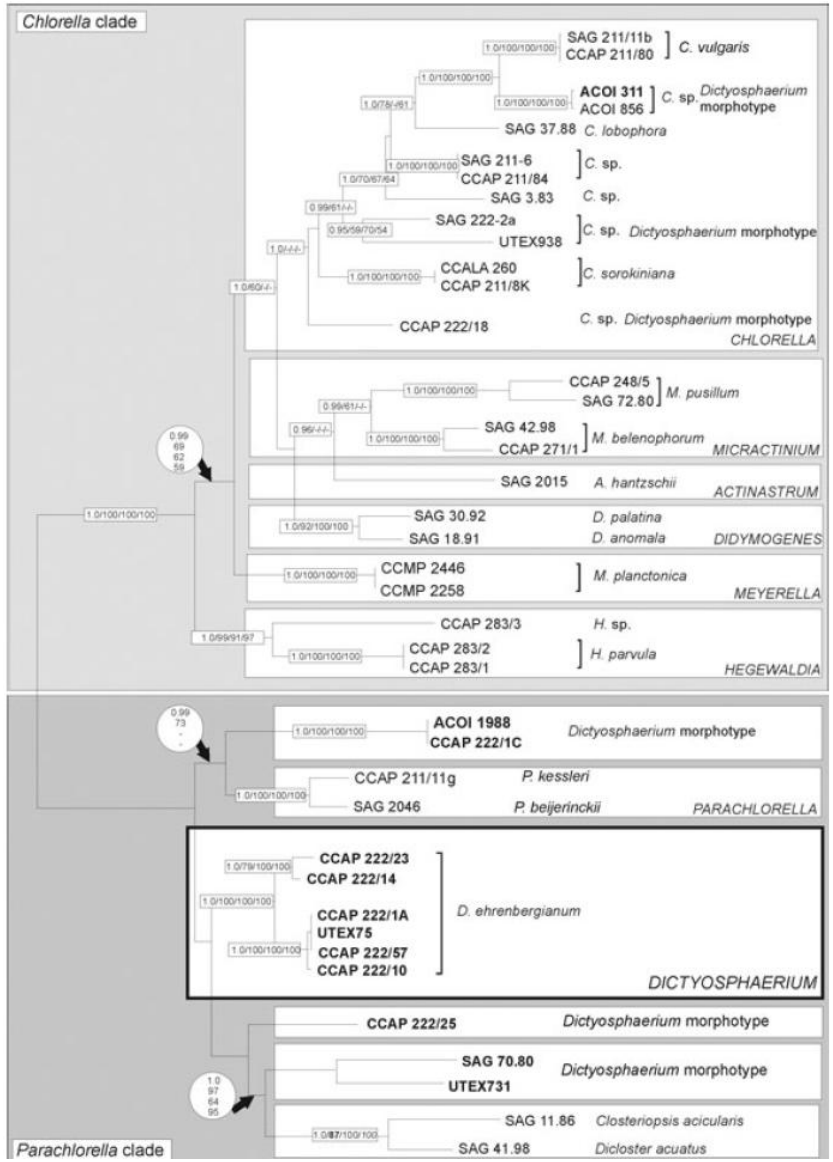




Trebouxiophyceae, Chlorellales

- Chlorella-clade + Parachlorella-clade
- *Dictyosphaerium* – highly polyphyletic genus

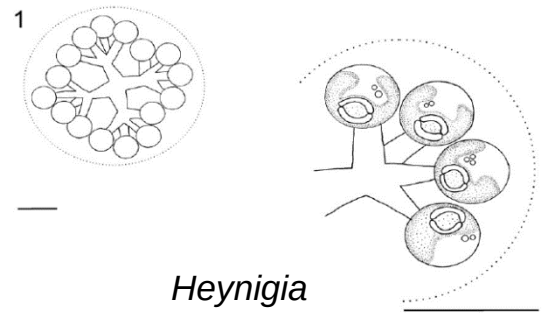




Krienitz et al. (2004): *Journal of Phycology* **46**, 559-563

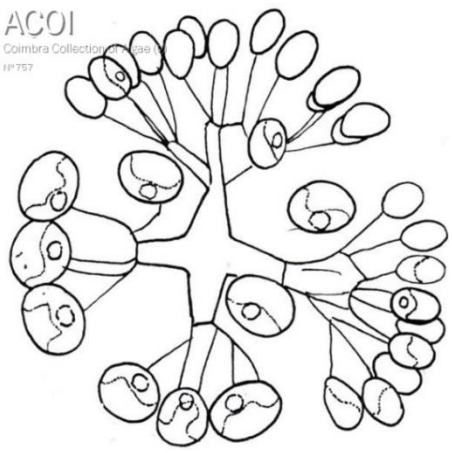
Dictyosphaerium

- 9 cryptic genera

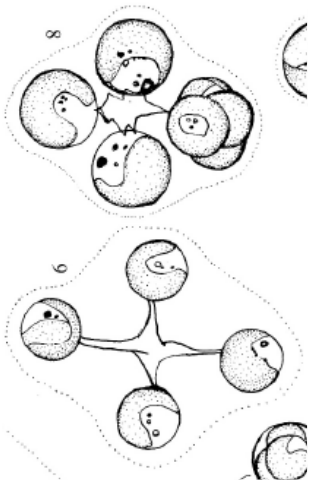


Heynigia

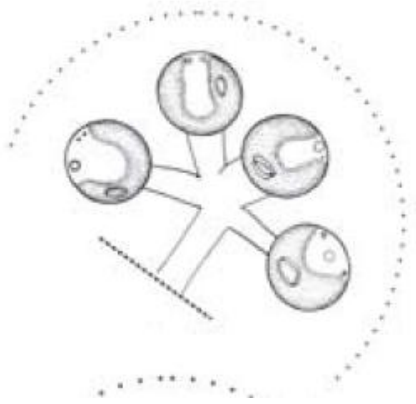
Hindakia

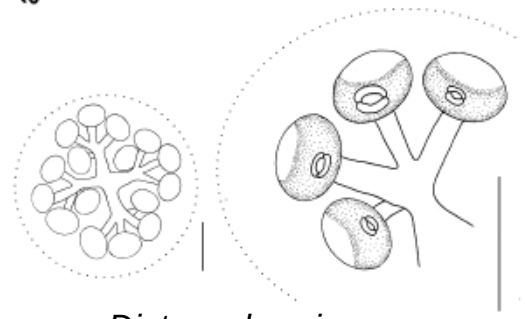


Mychonastes



Chlorella



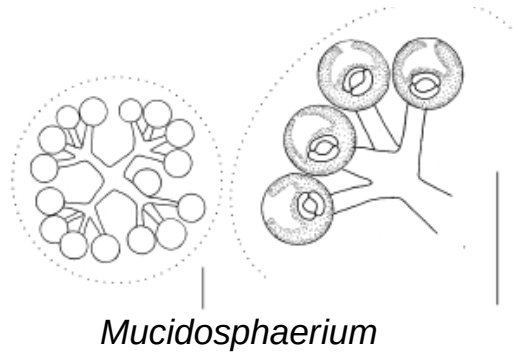


Dictyosphaerium

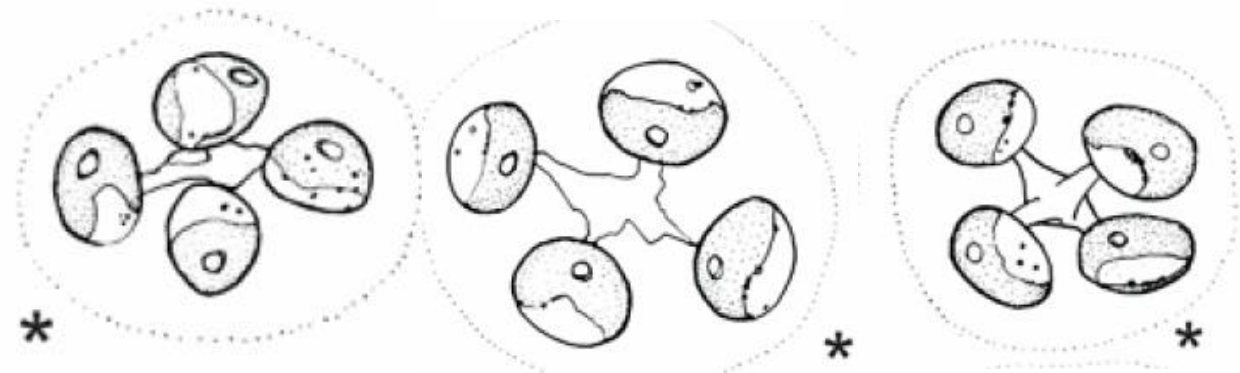
Compactochlorella

Kalenjinia

Masaia



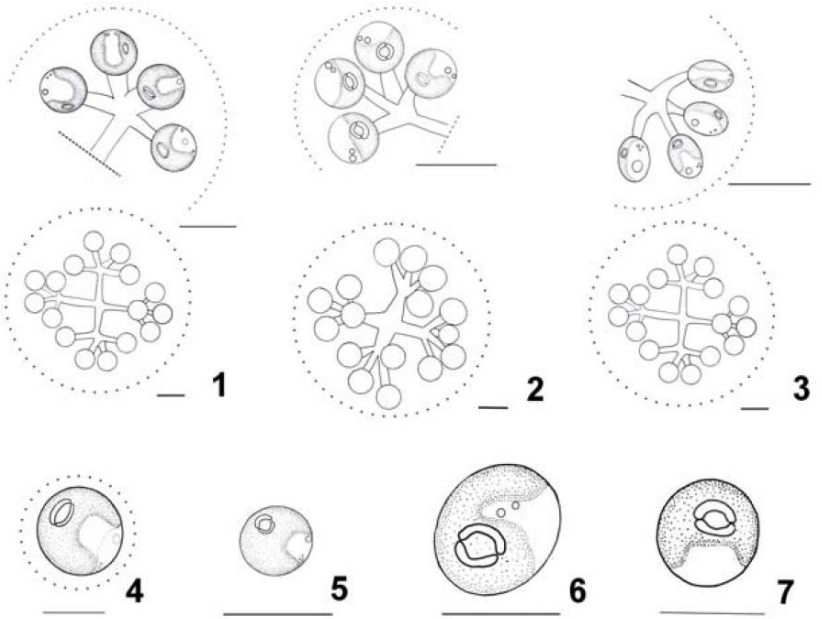
Mucidosphaerium



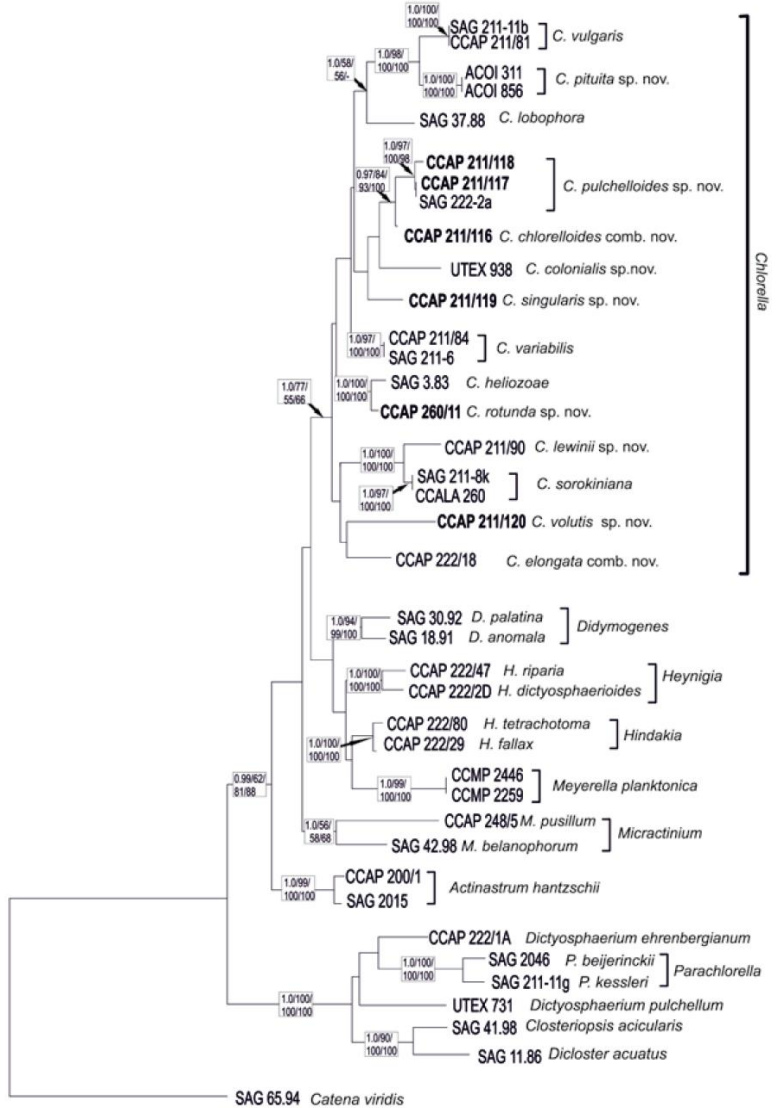
Krienitz et al. (2012): *Fottea* **12**, 231-253; Bock et al. (2010): *European Journal of Phycology* **45**, 267-277; Bock et al. (2011): *Journal of Phycology* **47**, 638-652; Krienitz et al. (2011): *Phycologia* **50**, 89-106

Trebouxiophyceae, Chlorellales

- Chlorella-clade
  - *Chlorella* – unicellular and colonial (*Dictyosphaerium*-like) species



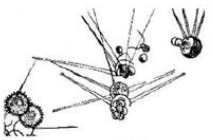
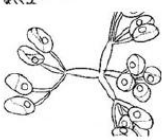
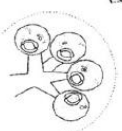
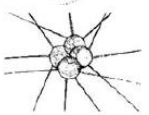
Figs 1–7. Drawings of light microscopical characters of *Chlorella* species. Iconotypes: (1) *Chlorella pituita,* authentic strain ACOI 311; (2) *Chlorella pulchelloides,* authentic strain CCAP 211/118; (3) *Chlorella coloniales,* authentic strain UTEX 938; (4) *Chlorella singularis,* authentic strain CCAP 211/119; (5) *Chlorella rotunda,* authentic strain CCAP 260/11; (6) *Chlorella lewinii,* authentic strain CCAP 211/90; (7) *Chlorella volutis,* authentic strain CCAP 211/120. Scale bars 10 μm.

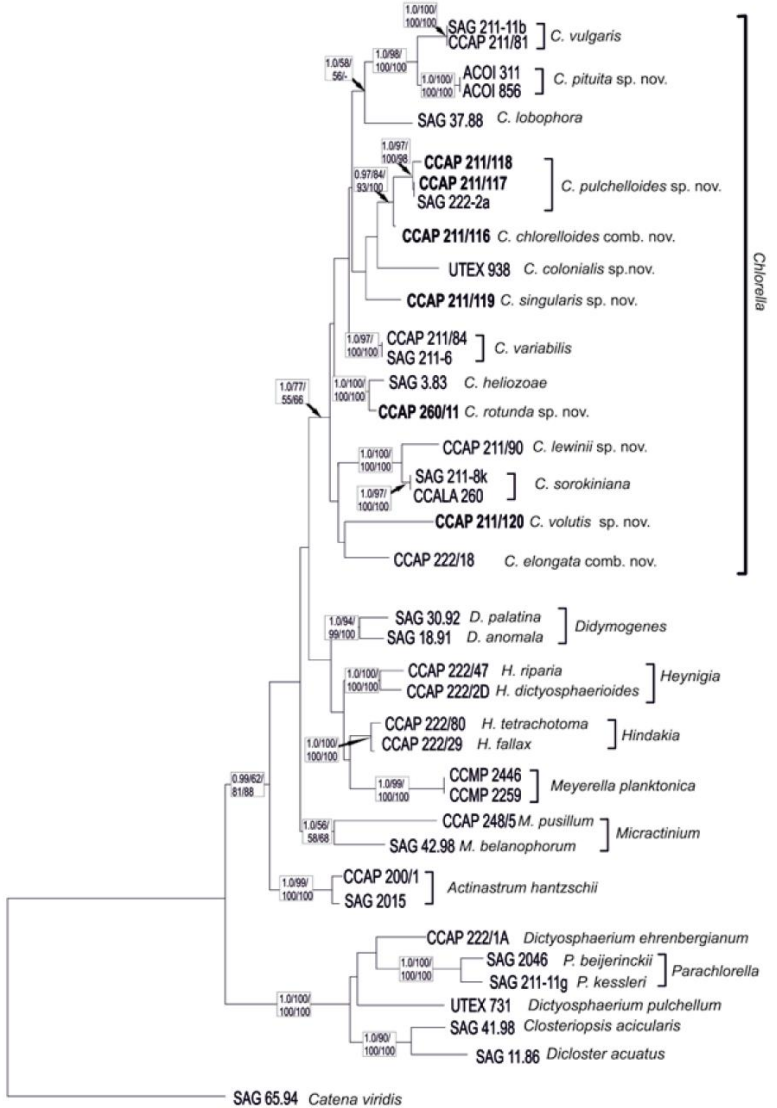


Bock et al. (2011): *Fottea* **11**, 293-312

Trebouxiophyceae, Chlorellales

- Chlorella-clade

Genus	Drawing	Main diacritic morphology
Actinastrum		Cells rod-shaped, elongated, radially arranged in coenobia
Chlorella		Spherical or broad oval cells, with one pyrenoid, solitary or in mucilage covered colonies
Didymogenes		Cells cylindrical curved with convex side attached in 2-, 4- or 16-celled coenobia, one pyrenoid, spines
Hegewaldia		Spherical cells with or without bristles, solitary or in colonies, 1 pyrenoid, facultative oogamy
Hindakia		Broad oval cells interconnected by strands attaching the apical pole, in mucilaginous colonies, 1 pyrenoid
Heynigia		Spherical cells interconnected by mucilaginous strands in mucilaginous colonies, 1 pyrenoid
Micractinium		Spherical cells with long bristles, in colonies, 1 pyrenoid
Meyerella		Cells short cylindrical, small, without mucilage, solitary, pyrenoid missing

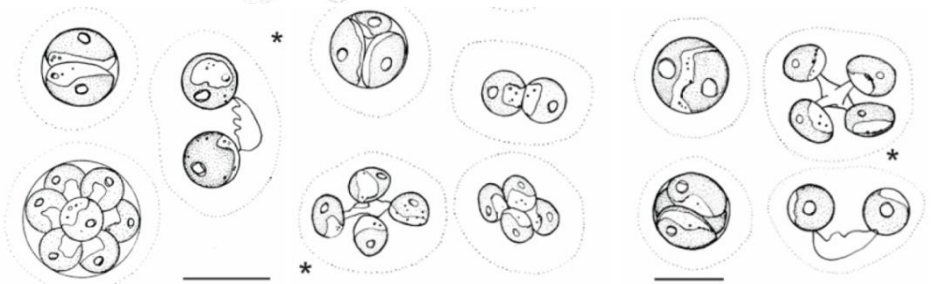


Krienitz & Bock (2012): *Hydrobiologia* **698**: 295 – 326

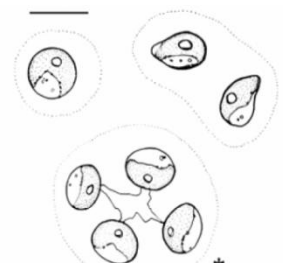
Trebouxiophyceae, Chlorellales

- Parachlorella-clade

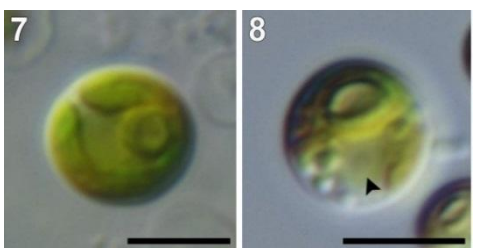
Closteriopsis	Needle-shaped cells with several pyrenoids in the lateral chloroplast, solitary
Dictyosphaerium	Broad oval cells interconnected by strands attaching the elongated cell side, in mucilaginous colonies
Dicloster	Cells ellipsoidal arcuated with convex sides attached in 2- or 4-celled coenobia, 1 or 2 pyrenoids
Mucidosphaerium	Spherical cells interconnected by mucilaginous strands in mucilaginous colonies, 1 pyrenoid
Parachlorella	Spherical cells covered by mucilage, solitary or in groups, 1 pyrenoid



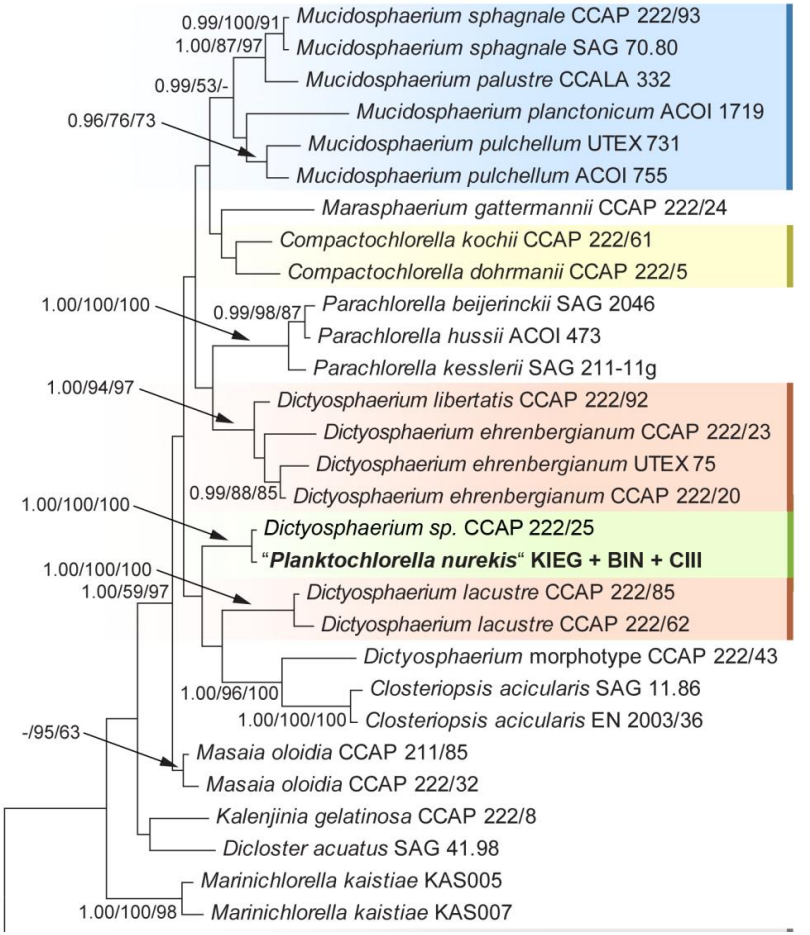
Marasphaerium *Compactochlorella* *Masaia*



Kalenjinia



Planktochlorella



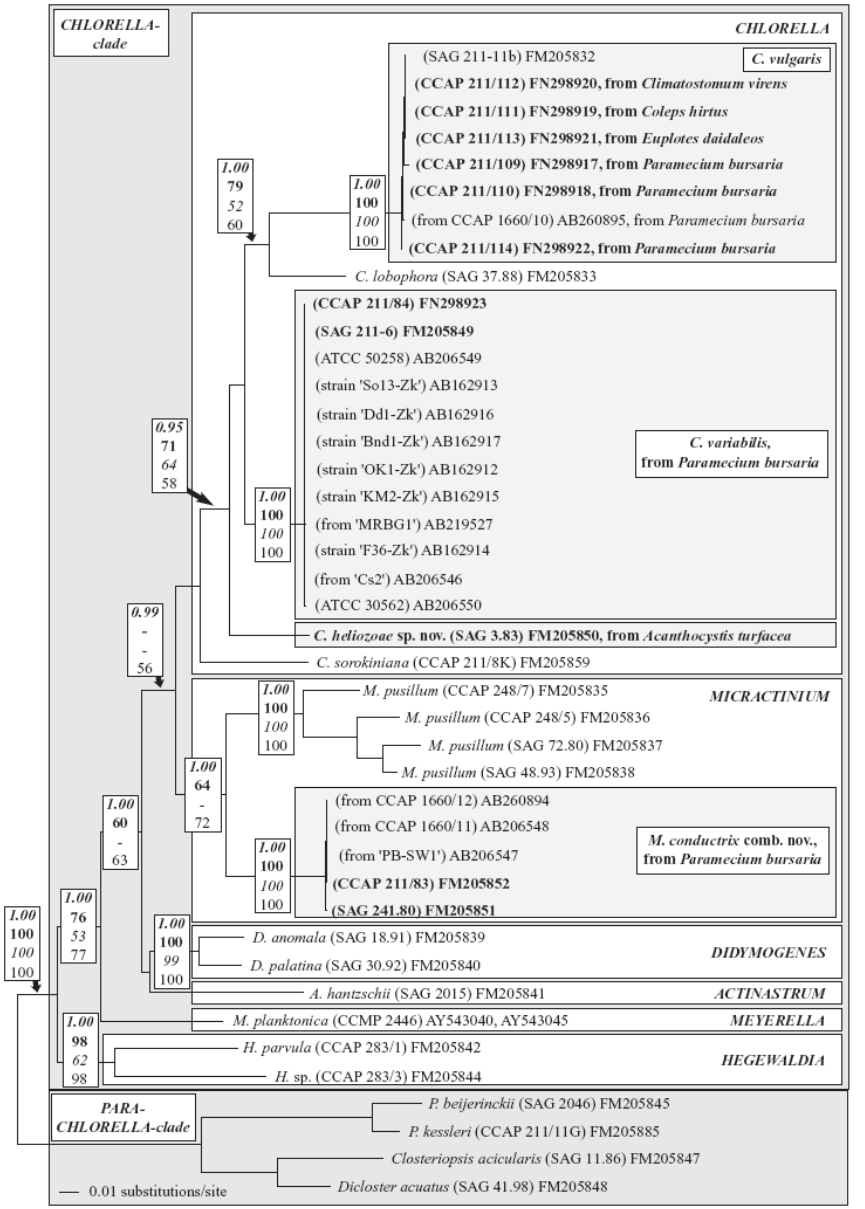
Krienitz & Bock (2012): *Hydrobiologia* **698**, 295 – 326; Krienitz et al. (2012): *Fottea* **12**, 231-253; Škaloud et al. (2014): *Fottea* **14**, 53-62

Trebouxiophyceae, Chlorellales

- ***Chlorella*-clade**
  - symbionts

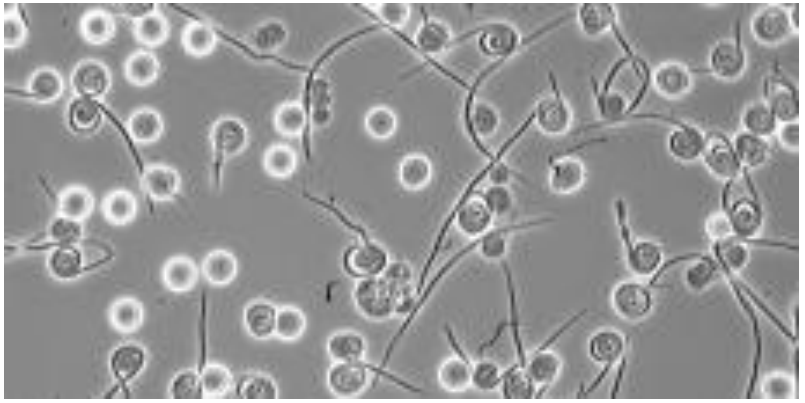
environmental microbiology
Environmental Microbiology (2010)
doi:10.1111/j.1462-2920.2010.02333.x

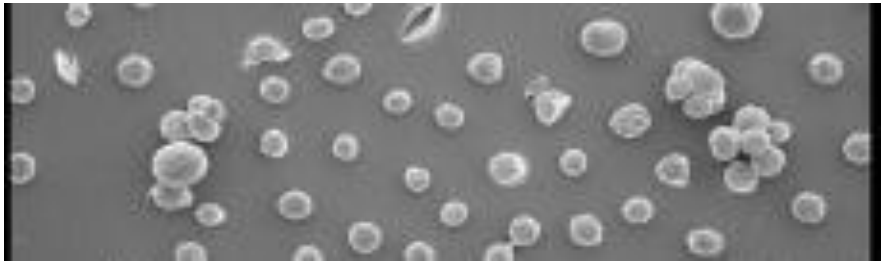
The systematics of *Zoochlorella* revisited employing an integrative approach

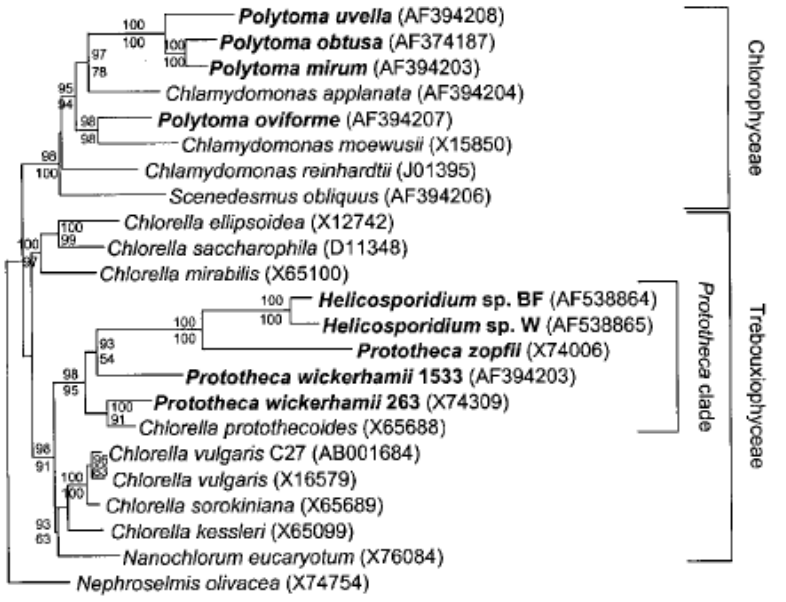


Chlorellales, *Helicosporidium*

- parasitic organism, described from insect larvae (1921)
- classified to Protozoa, then Fungi
- 18S rRNA analysis – Trebouxiophyceae
- autosporogenesis

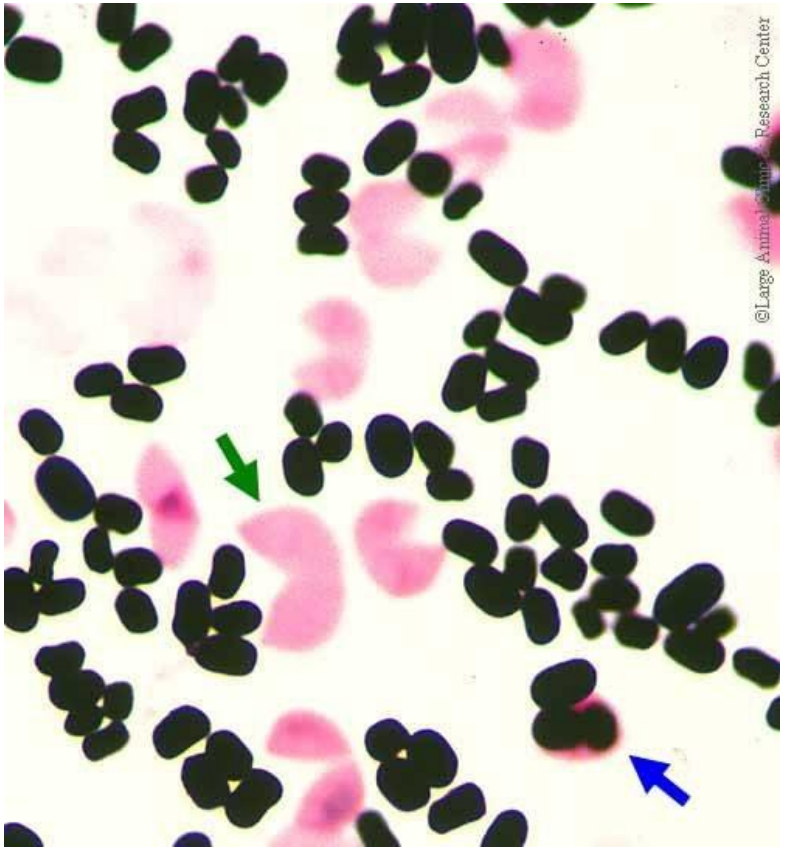






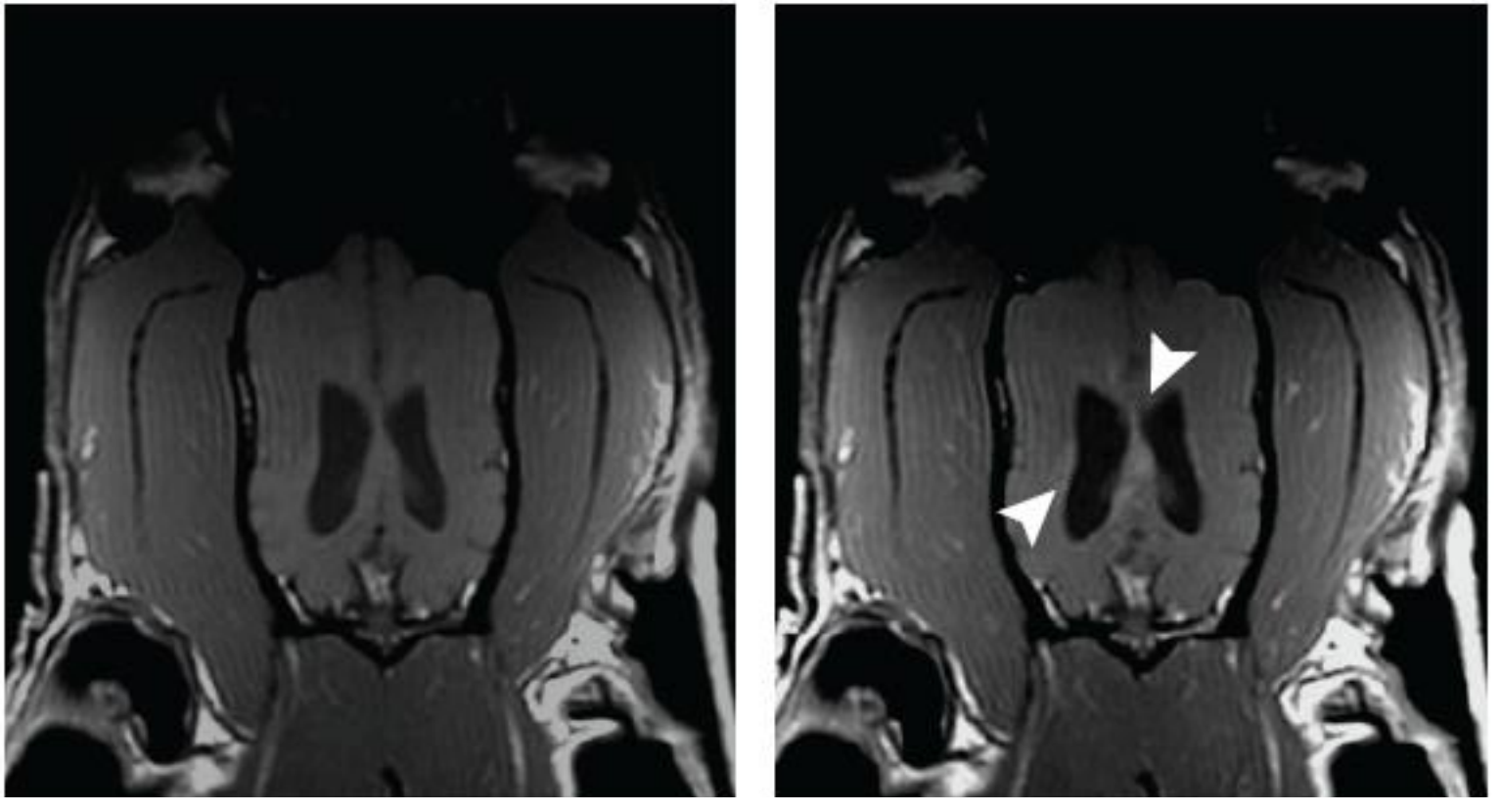
Chlorellales, *Prototheca*

- heterotrophic, pathogenic organism
- *protothecosis*



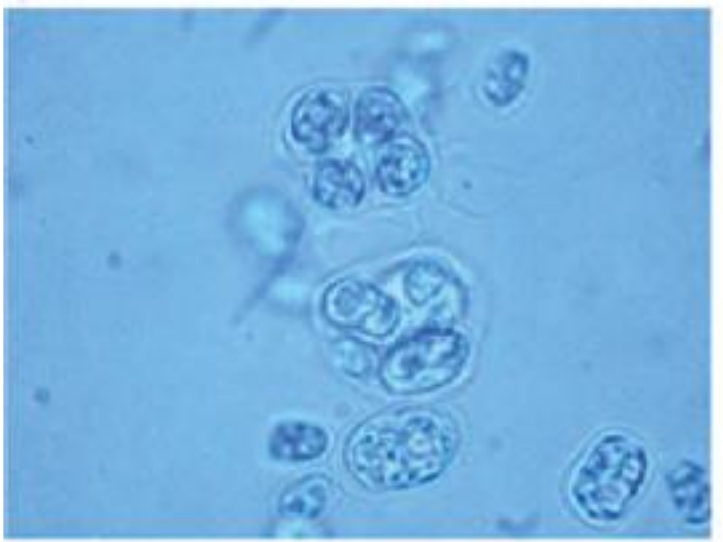
Prototheco sis

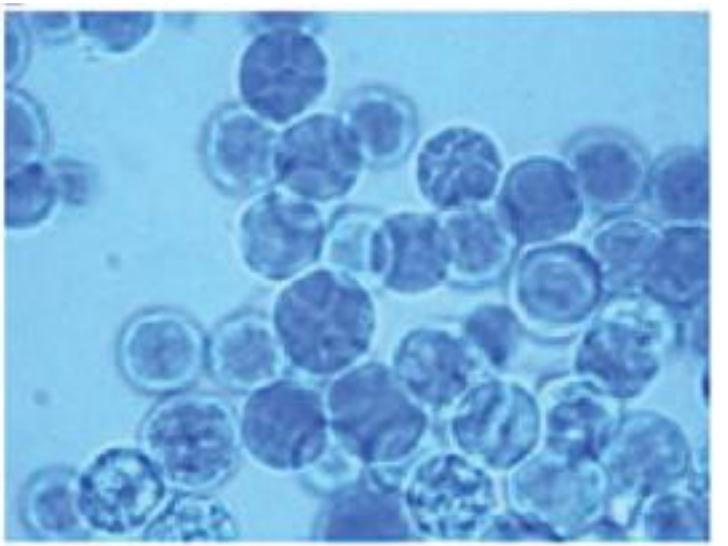
- 6-year-old dog: malfunction of coordination
- surgery of cranial tendon prior the disease
- magnetic resonance – brain lysis (meningoencefalitis)
- the dog was put to death



Protothecosis

- humans – infections from soil, water, ...
- skin at immunosupresive patients
- first incidence - 1964 (Sierra Leone – foot lysis)
- mortality 2,2%





Chlorellales, practical use

- high growth rate – a popular model organism
- *Chlorella* has the highest chlorophyll content from al studied genera
- large scale cultivations

Chlorellales, practical use

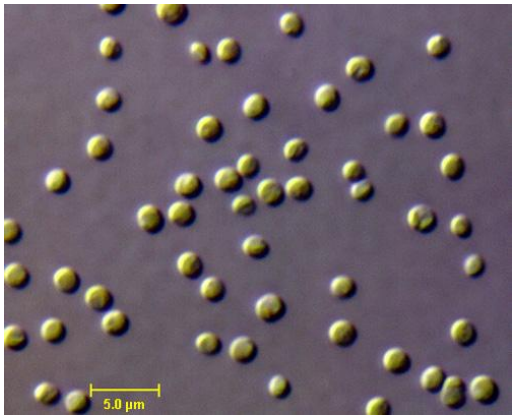
- **chlorophyll:**
  - anti-inflammatory effects, supportswound healing
  - elimination of heavy metals and toxins
  - anaemia therapy
  - anti-tumor activity
  - supports immune system
  - reducing high blood pressure

Chlorella tabs

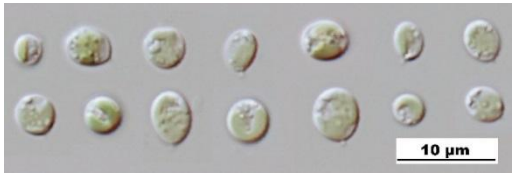
Trebouxiophyceae, picoplankton

- green balls up to 3 μm in diameter

Nannochloris

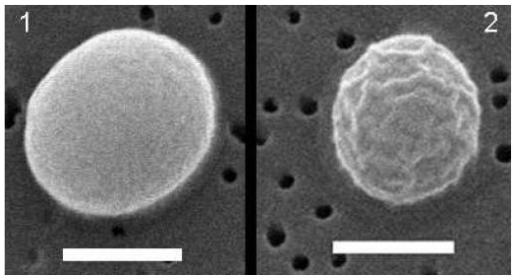


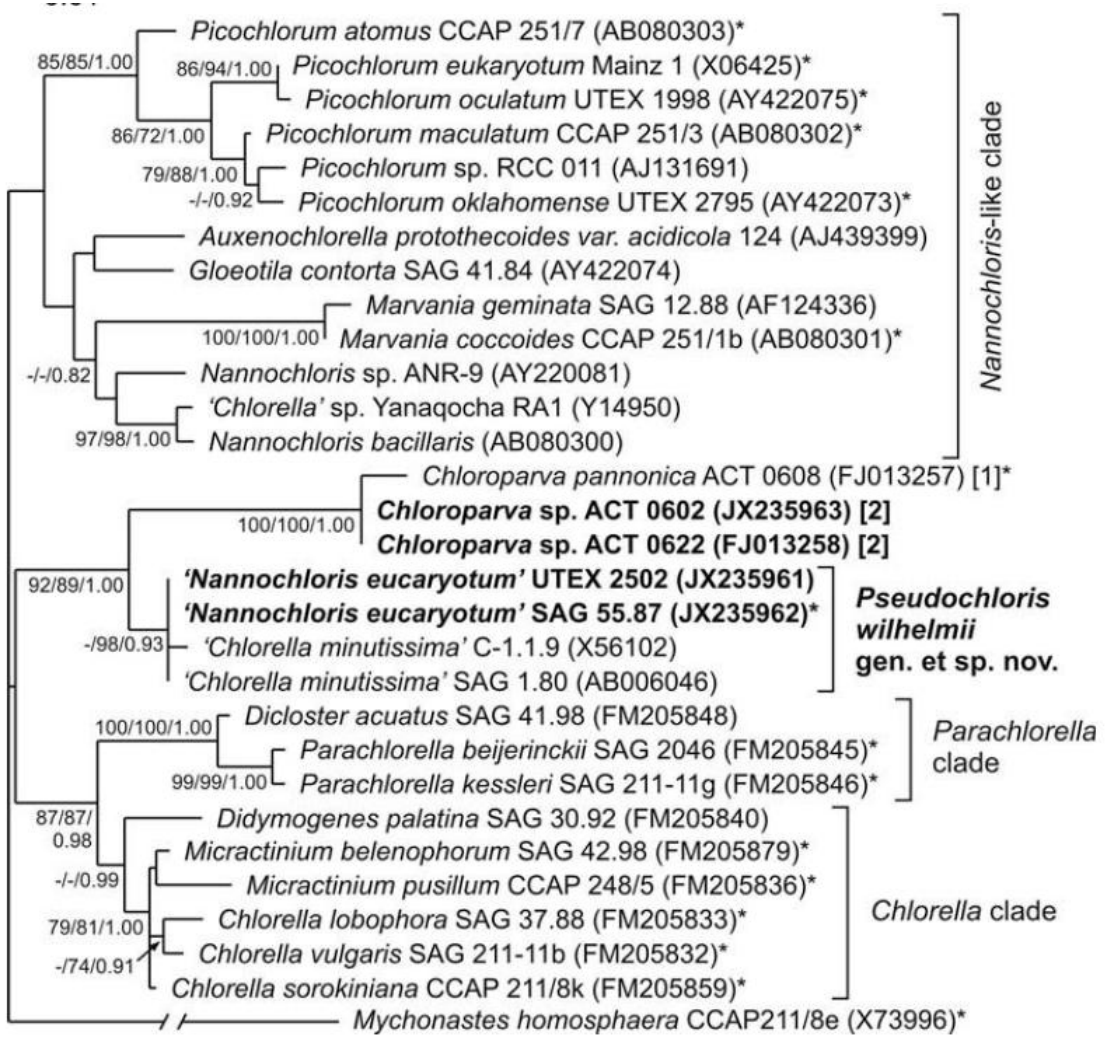
Picochlorum



Pseudochloris

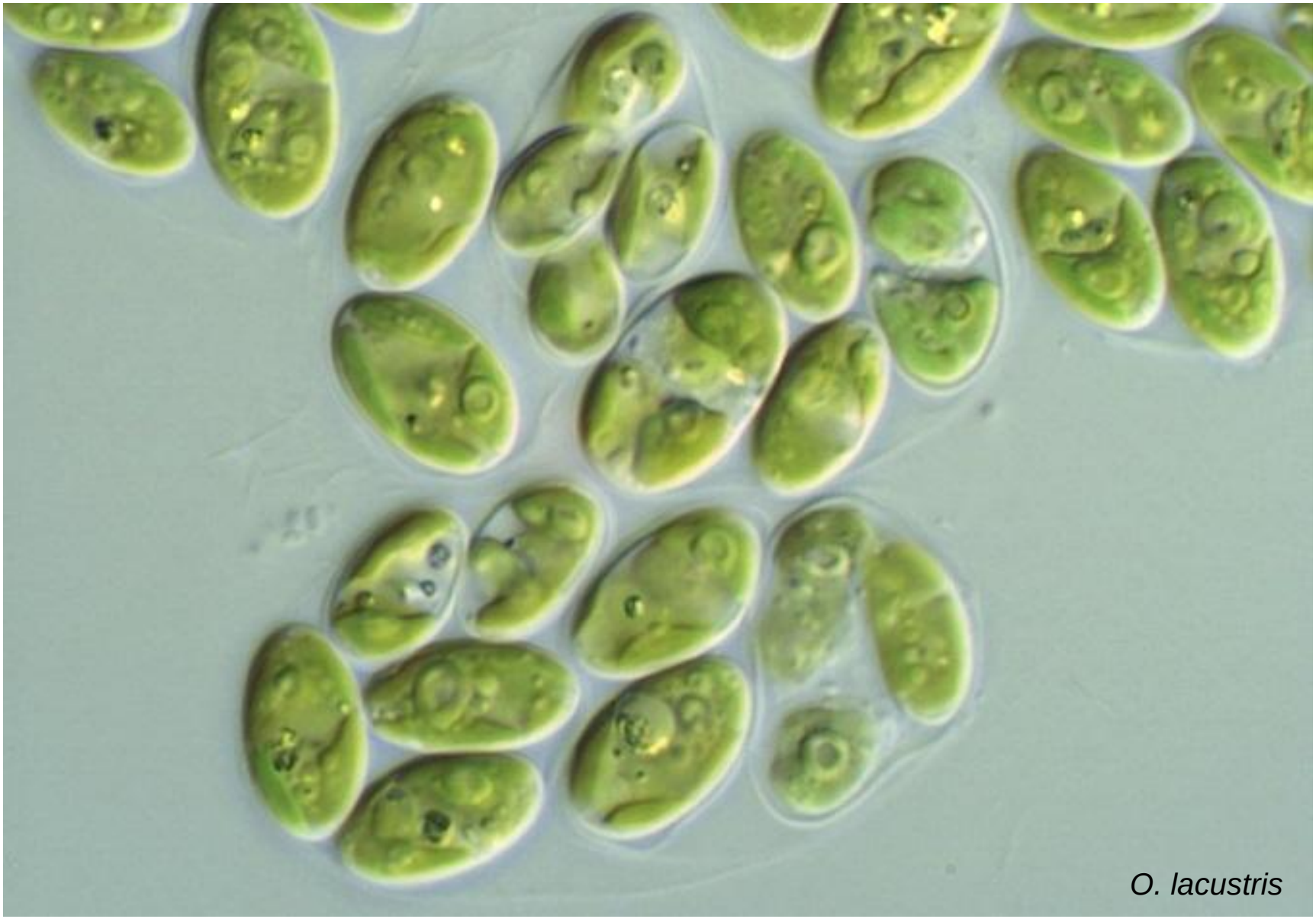
Chloroparva



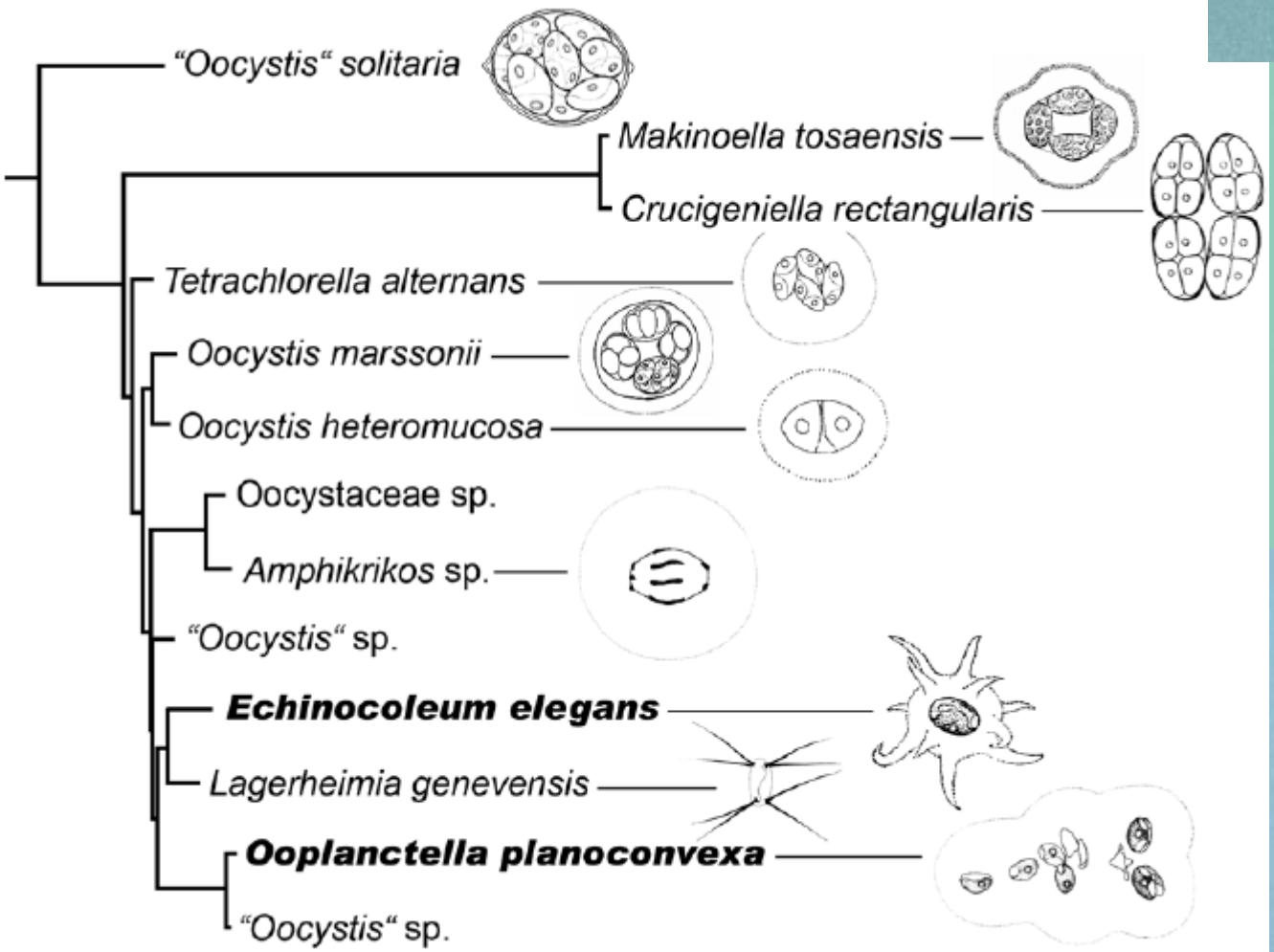


Somogyi et al. (2013): European Journal of Phycology 48, 427-36

Chlorellales, Oocystaceae, *Oocystis*



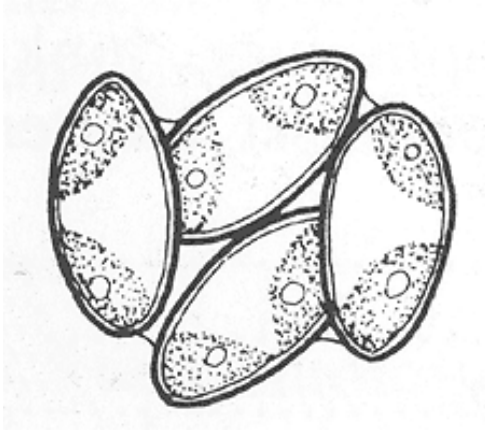
Chlorellales, Oocystaceae, *Oocystis*



Chlorellales, Oocystaceae

Makinoella

Crucigeniella

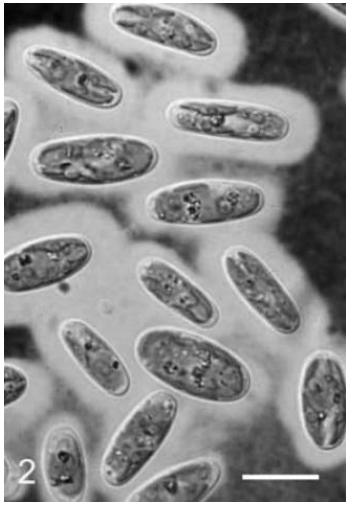


Tetrachlorella

Amphikrikos

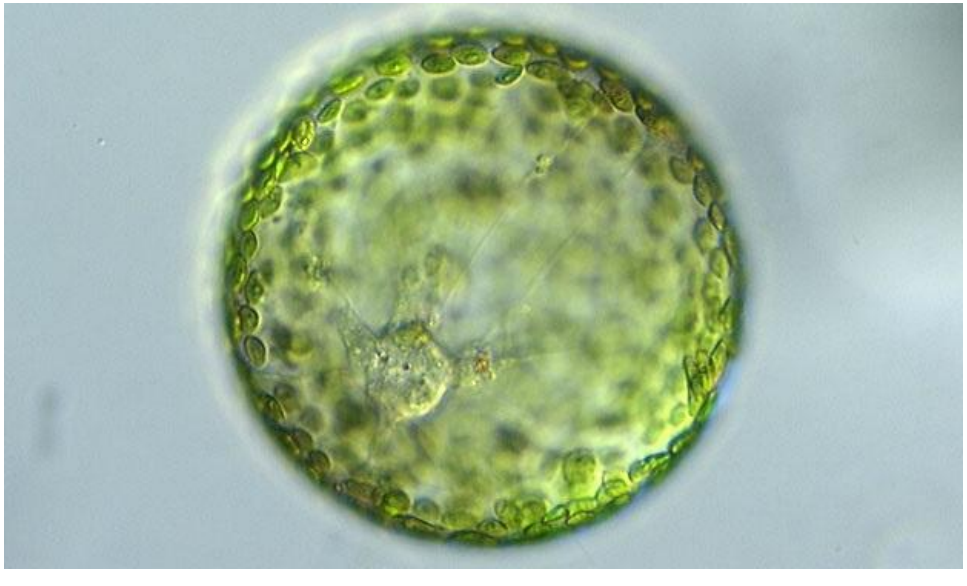
Lagerheimia

Echinocoleum



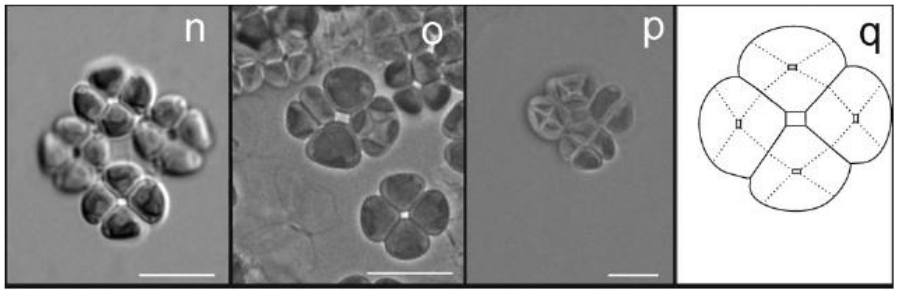
Elongatocystis

Chlorellales, Oocystaceae, *Eremosphaera*

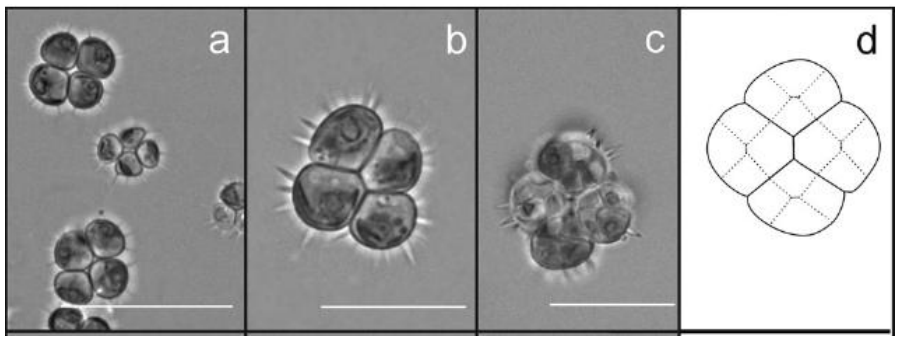


Trebouxiophyceae, tetrahedric colonies

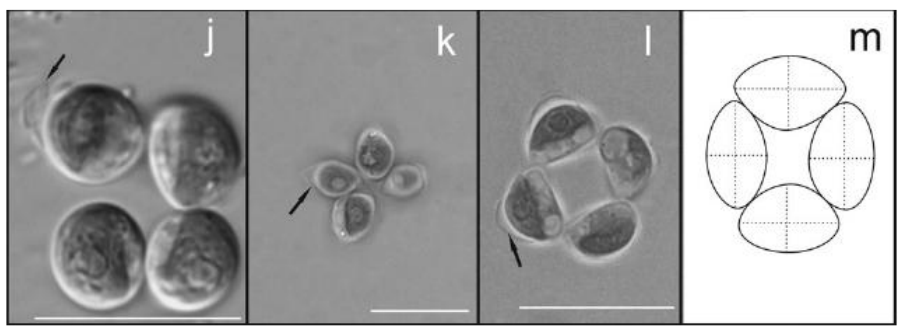
Lemmermannia – smooth colonies, small aperture

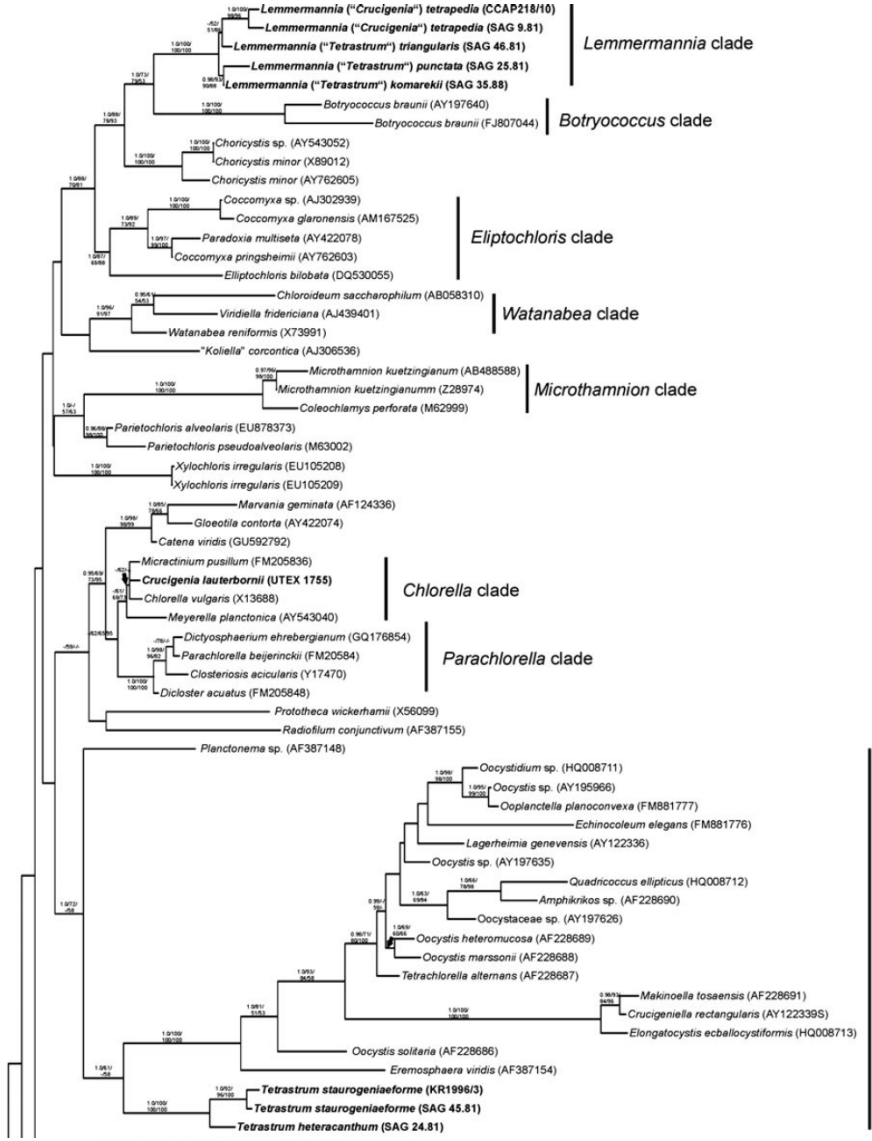


Tetrastrum – spiny colonies



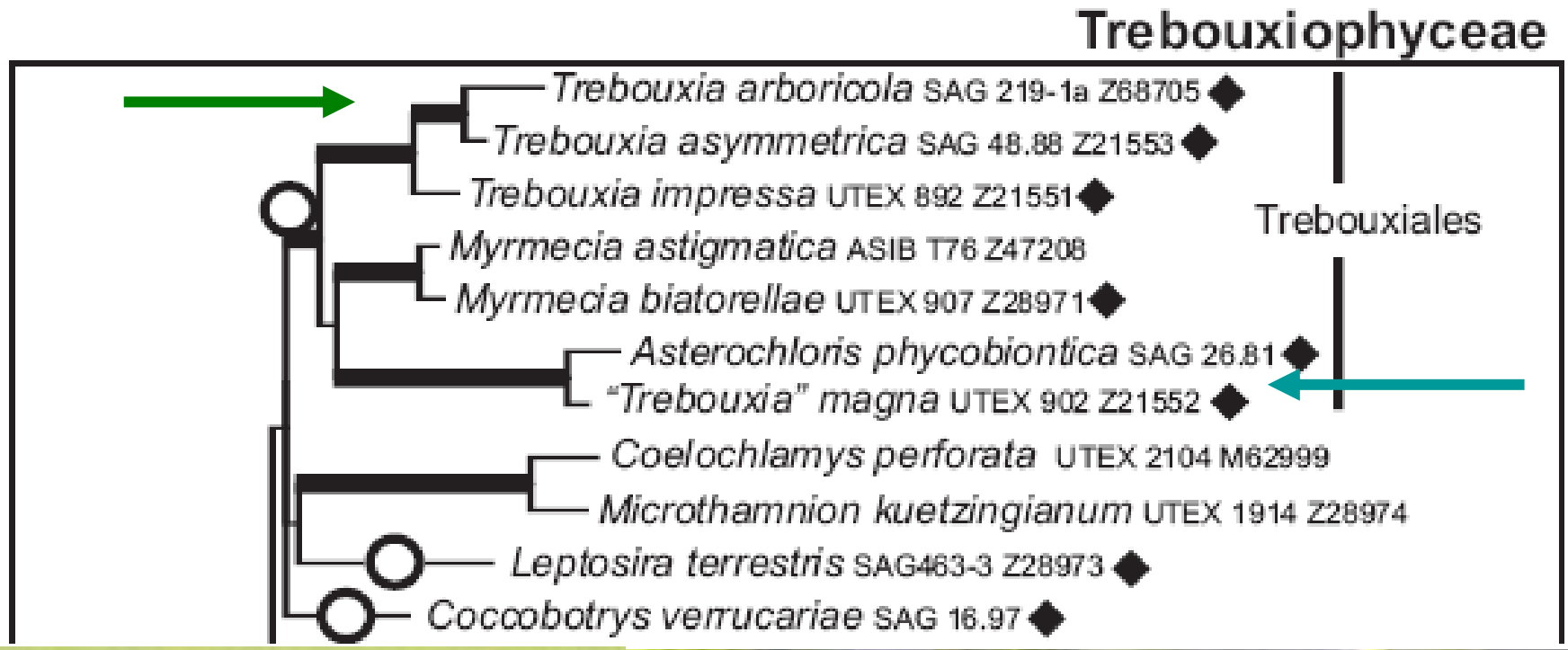
Crucigenia – smooth colonies, big aperture

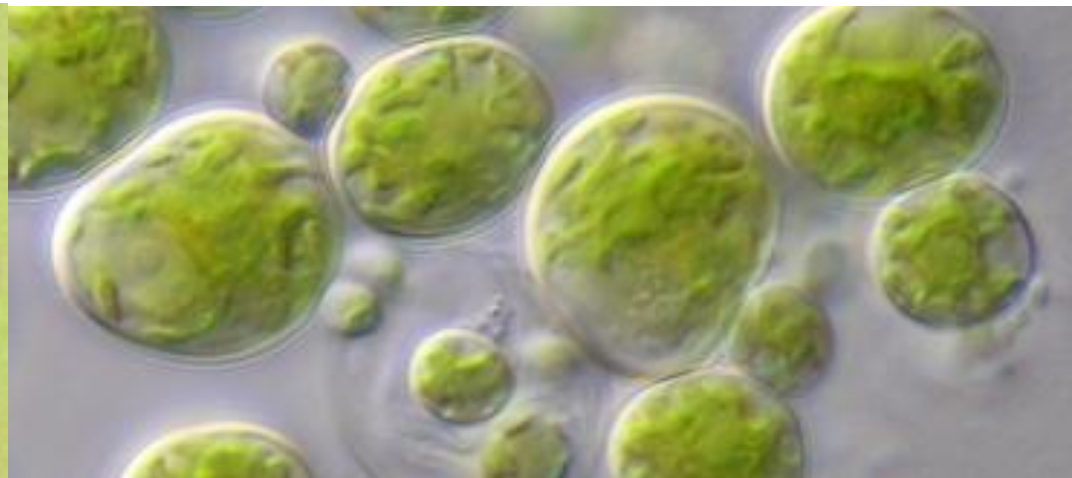




Bock et al. (2013): *Journal of Phycology* **49**, 329 – 339

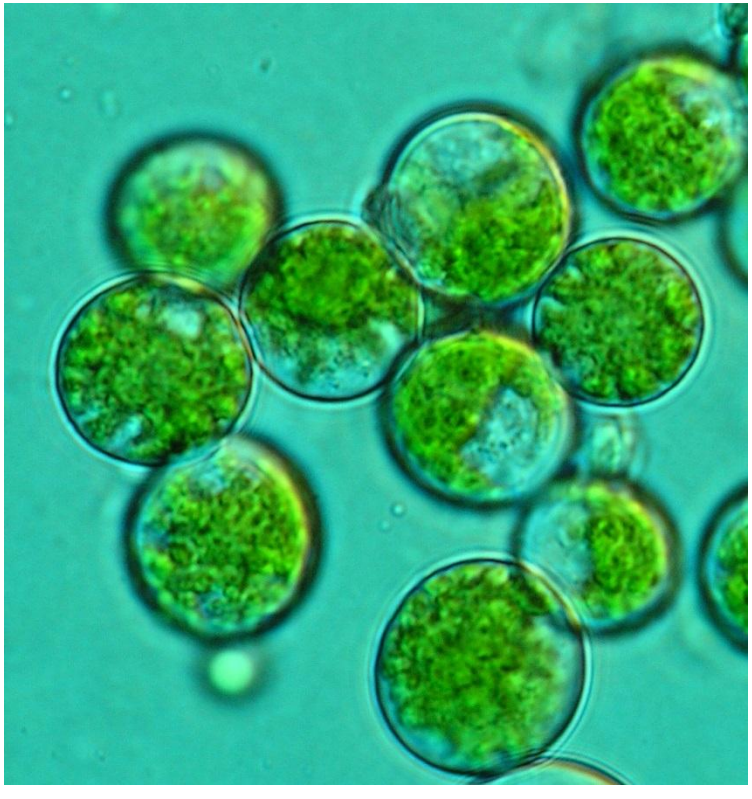
Trebouxiales

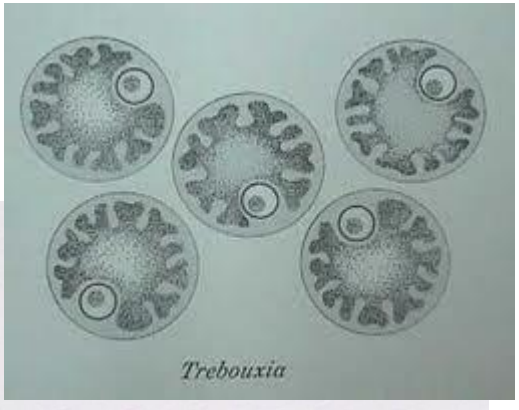


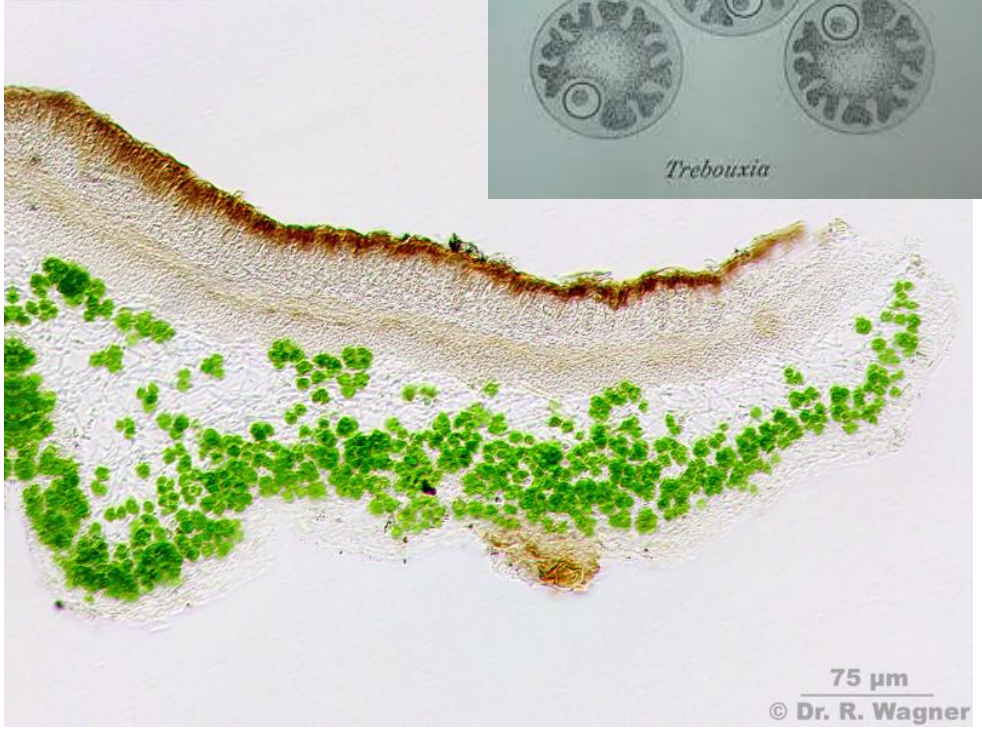


Trebouxiales, *Trebouxia*

- lichen endosymbiont, probably free-living, as well (bark)
- coccoid green alga with a central, asteroid plastid
- autospores, zoospores







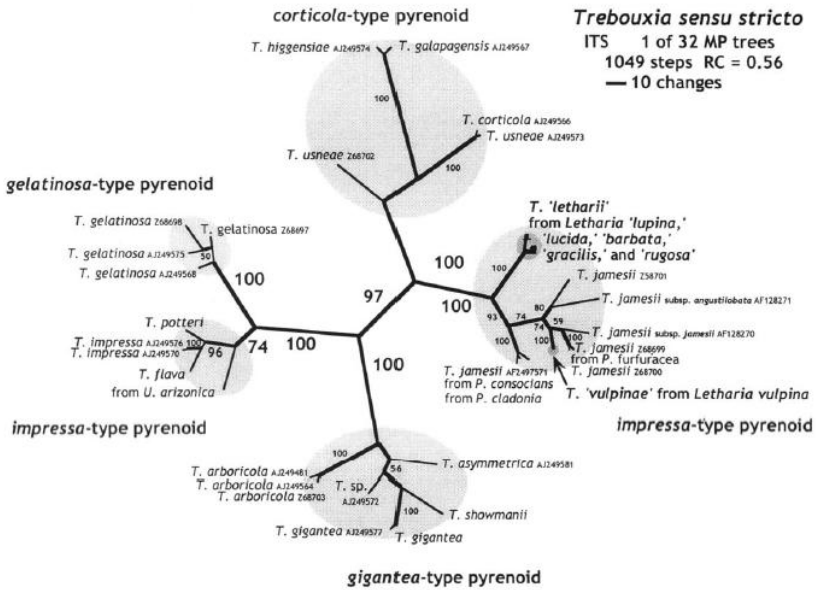
Trebouxiales, *Trebouxia*

Trebouxiales, *Trebouxia*

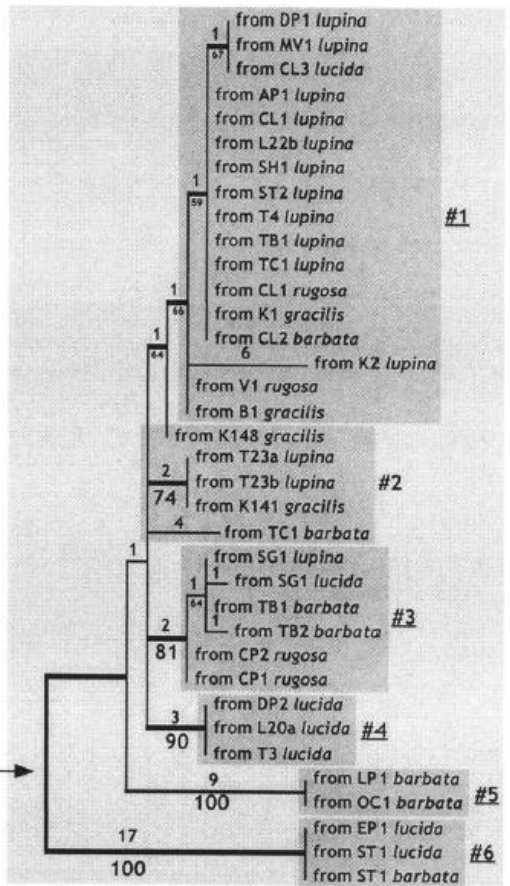
Phylogenetic Species, Reproductive Mode, and Specificity of the Green Alga Trebouxia Forming Lichens with the Fungal Genus Letharia

Scott Kroken; John W. Taylor

The Bryologist, Vol. 103, No. 4. (Winter, 2000), pp. 645-660.

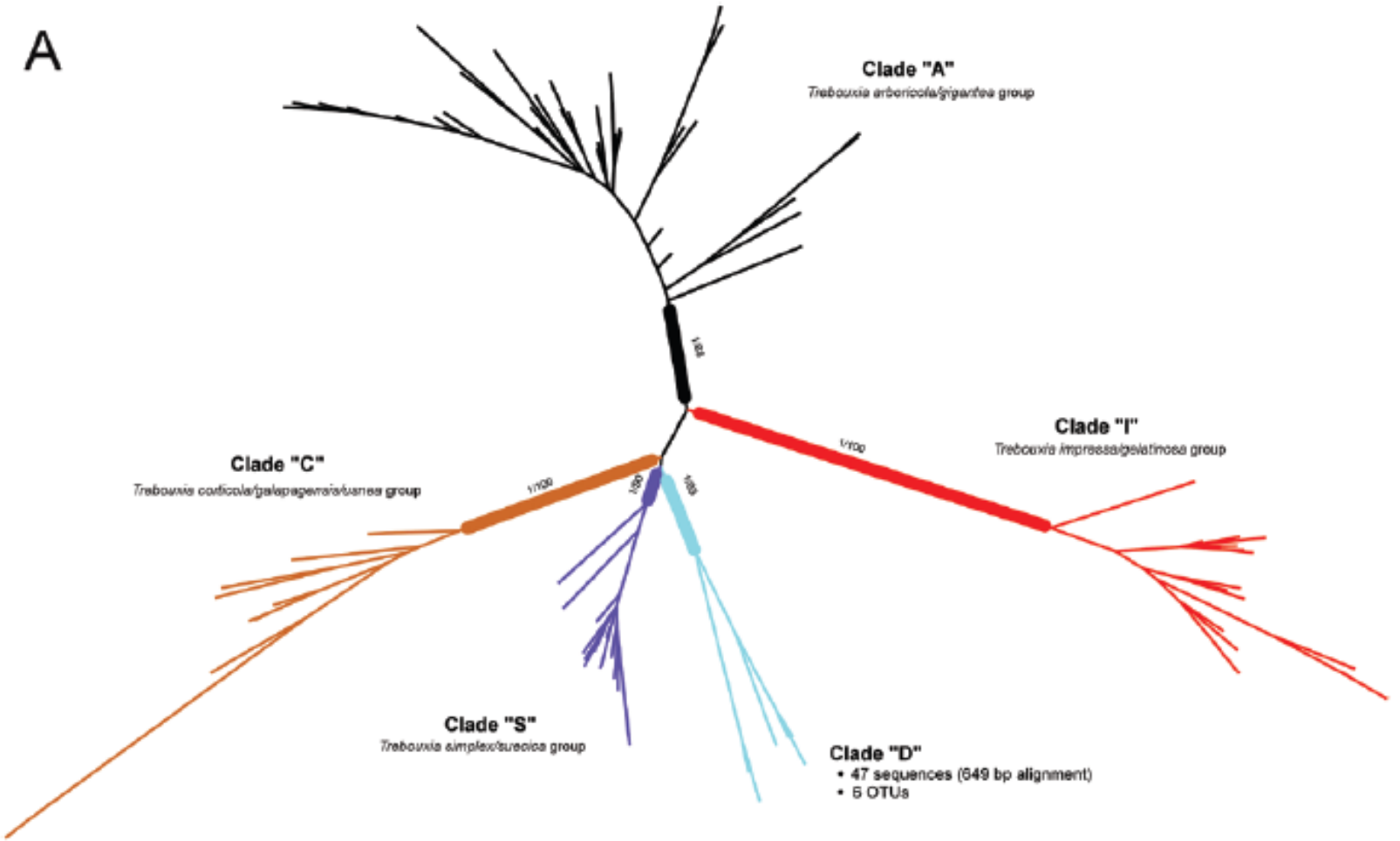


Trebouxia jamesii **species complex**
actin I intron 569
1 of 8 MP trees
51 steps
RC = 0.95



Cryptic diversity **– e.g.** ***T. jamesii***

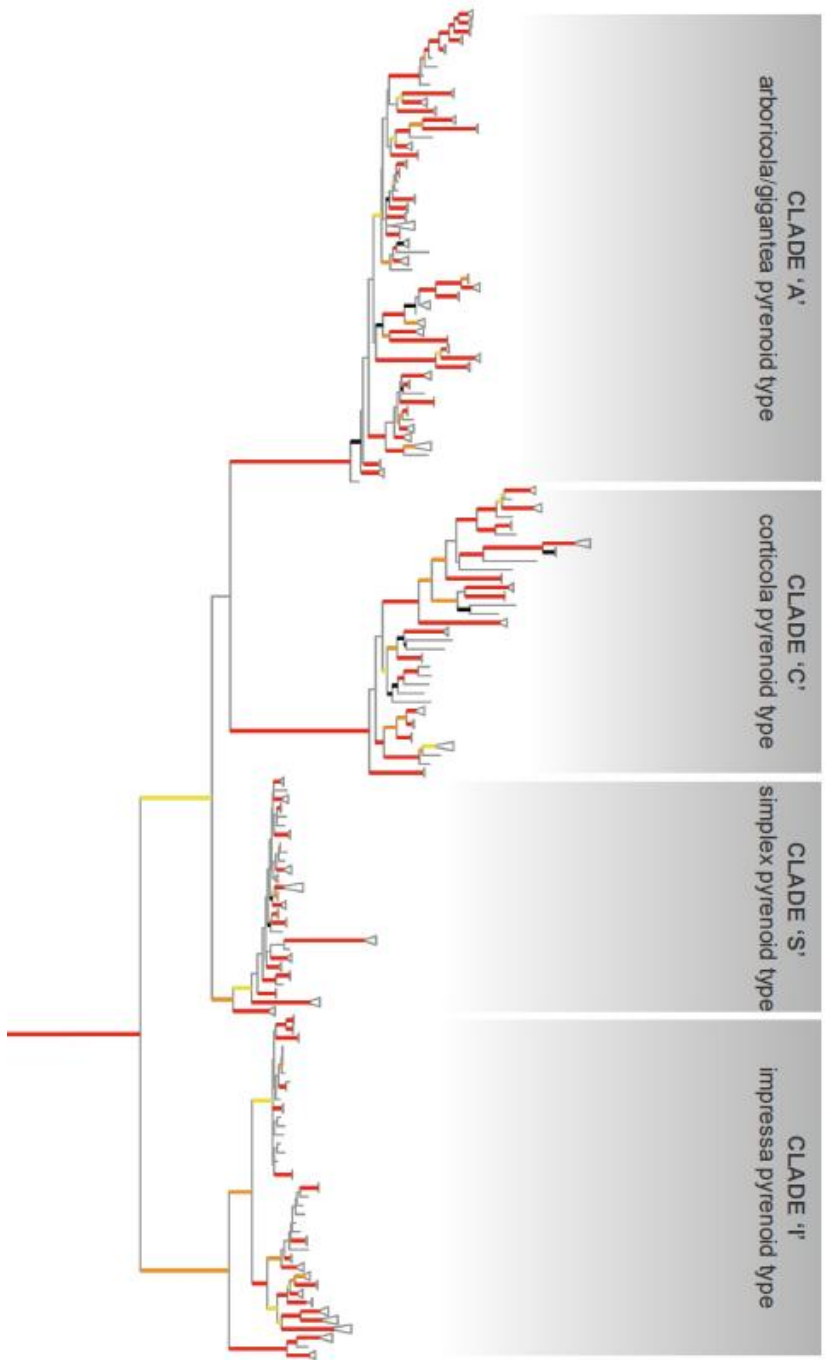
Trebouxiales, *Trebouxia*

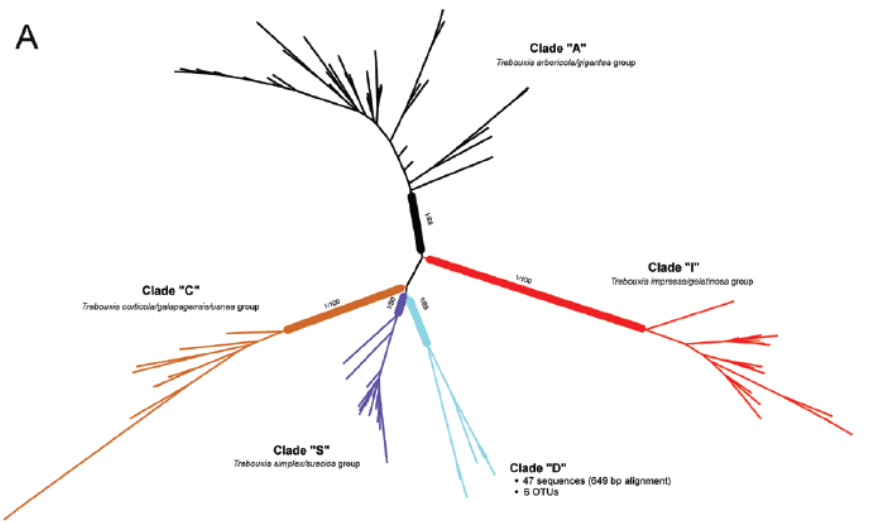


Xu et al. (2020): *Botanical Journal of the Linnean Society* **XX**, 1 – 9

Trebouxiales, *Trebouxia*

- 29 species described so far
- in reality, there is at least 111 species-level lineages



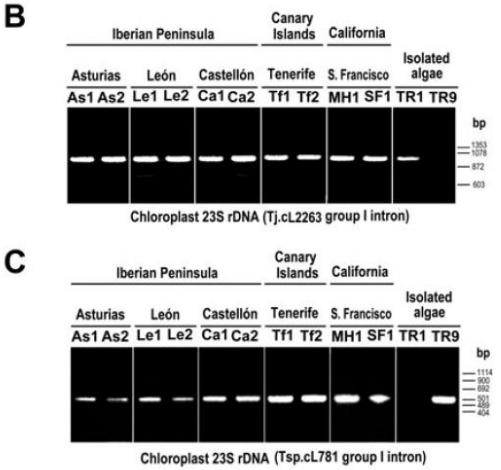


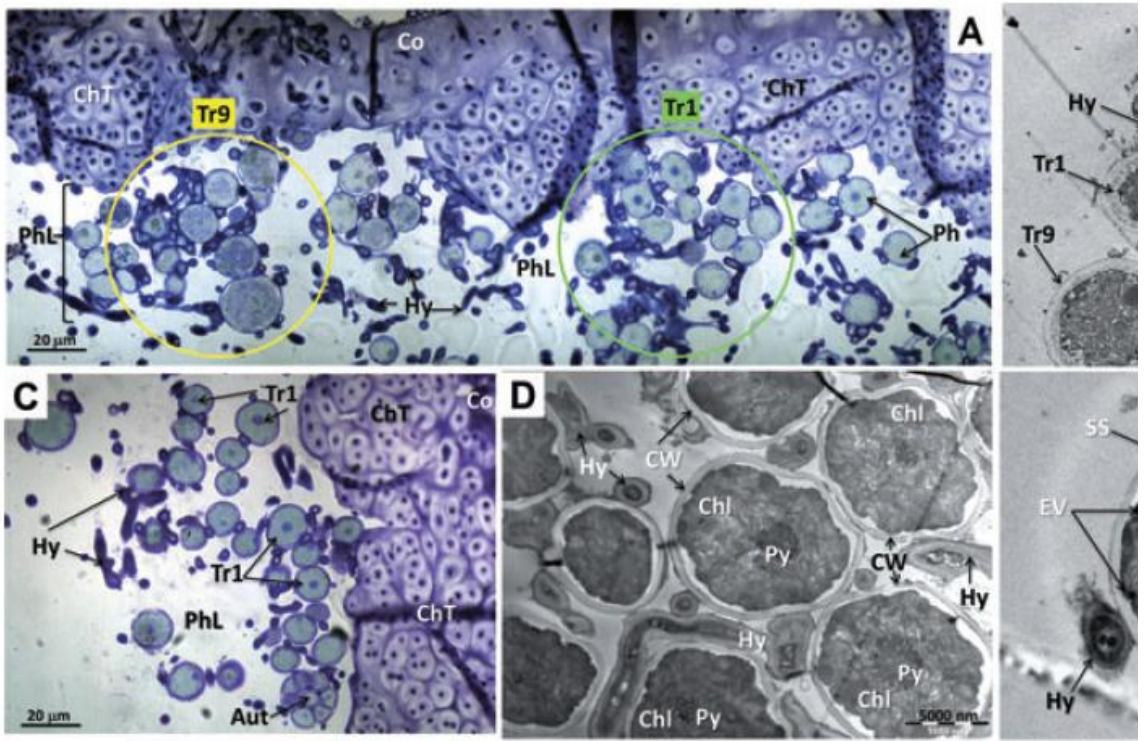
Muggia et al. (2020): *Molecular Phylogenetics and Evolution* **149**

Trebouxiales, *Trebouxia*

Casano et al. (2011): co-existence of two physio-logically distinct algae

- TR1: cold-requiring
- TR9: warm-requiring (thermophilic)





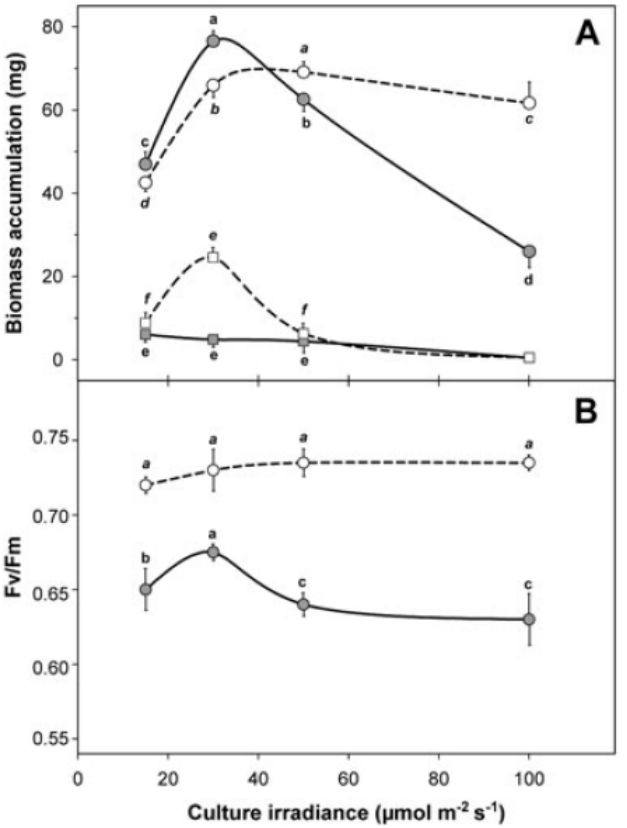


Fig. 4. Effects of temperature and irradiance during culture on growth and photosynthesis in isolated TR1 and TR9 phycobionts. A. TR9 and TR1 biomass accumulation after 30 days of culture at 17°C or 20°C and the indicated irradiances. Grey and white circles represent TR1 and TR9 phycobionts cultured at 17°C respectively. Grey and white squares represent TR1 and TR9 phycobionts cultured at 20°C respectively. Data are the mean values of five independent replicates (+ or –SD).
B. Maximum quantum yield of PSII (F_v/F_m) of TR1 and TR9 phycobionts cultured at 17°C and four different light intensities during 30 days. Data are the mean values of five independent replicates (± SD). Grey and white circles represent TR1 and TR9 phycobionts respectively. Different normal and italic letters indicate significant differences among culture conditions for TR1 and TR9 phycobionts respectively (LSD test).

Trebouxiales, *Trebouxia*

Del Campo et al (2013) – ecological speciation of mycobionts and photobionts

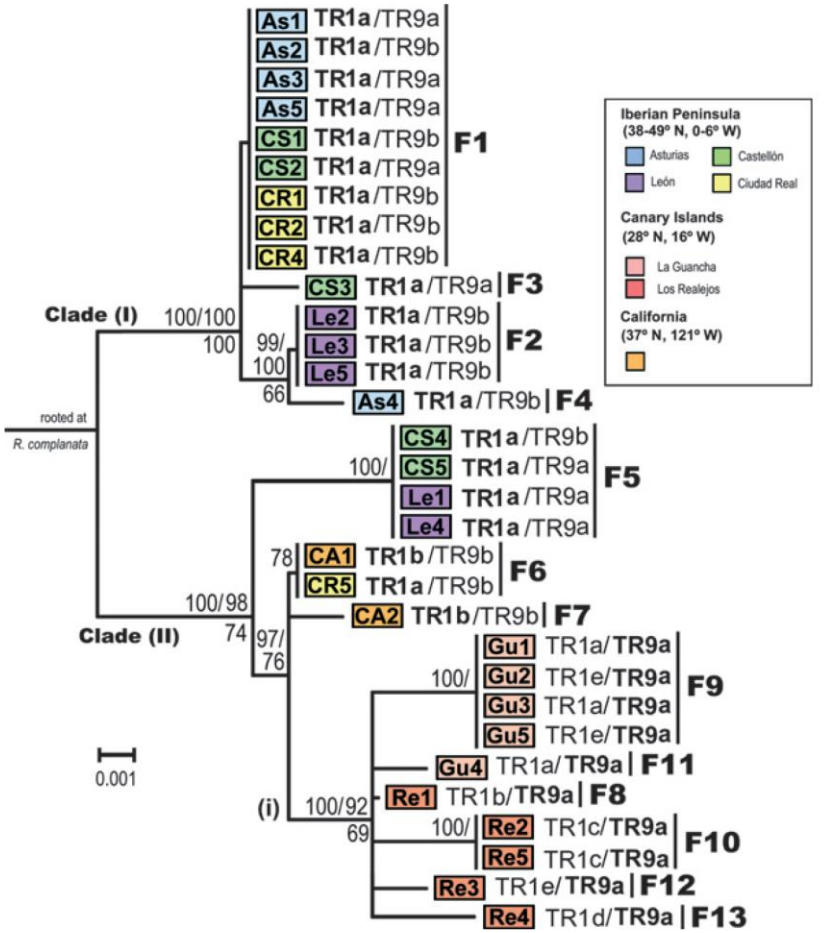
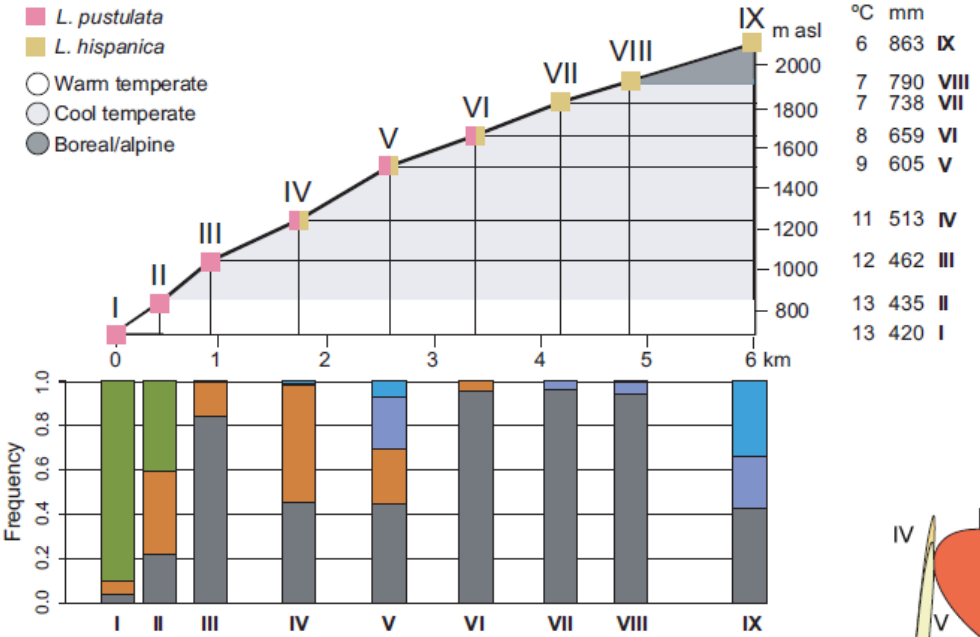
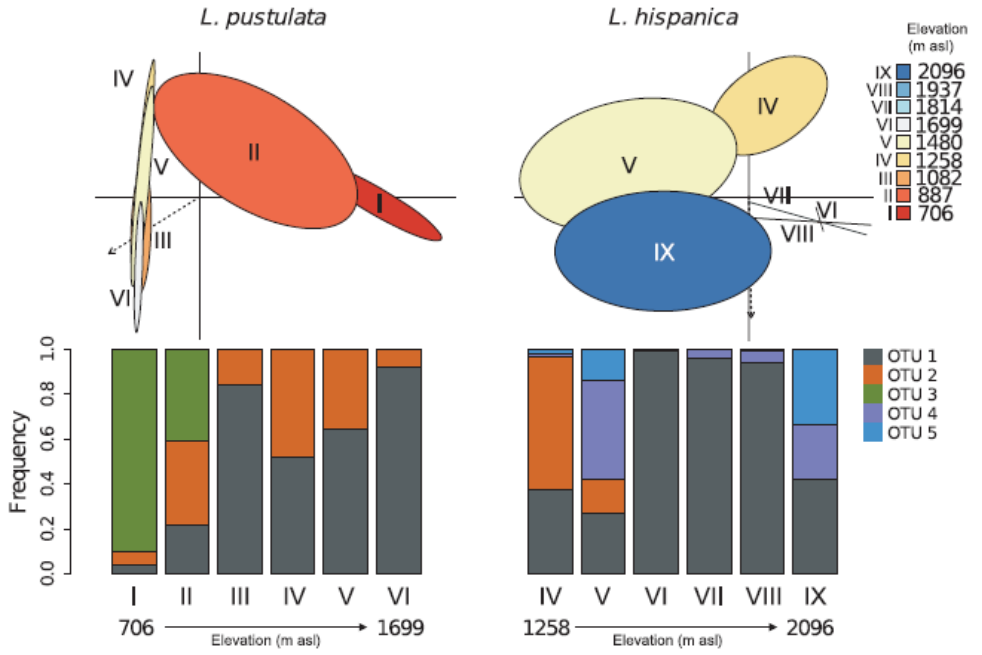


Fig. 1. Phylogram based on the analysis of fungal nrITS and *rpb2* gene sequences in specimens of *Ramalina farinacea*, with *Ramalina complanata* as out-group (accession numbers FJ356152 and DQ883762 for nrITS and *rpb2*, respectively). Vertical bars on the right indicate different fungal haplotypes of F1–F13. Algal haplotypes are indicated at the right of each sample: TR1 haplotypes based on nrITS sequences (TR1a–TR1e) and TR9 haplotypes based on nrITS sequences (TR9a–TR9b) are indicated at the left and the right of the slash-marks, respectively. The predominant phycobiont associated with each fungal haplotype is noted in bold letters. Subclade (i) includes mycobionts from the Canary Islands. The tree was obtained using a Bayesian approach with BEAST. Values at the left and right of the slash-mark on the tree branches correspond to posterior probabilities inferred with Bayesian and MP methods, respectively. Below the branches are the bootstrap values recorded only for those lineages supported by 50% of all (1000) replicates. Subpopulations within the studied populations (the Iberian Peninsula, the Canary Islands and California) and their coordinates are shown in the inset.

Trebouxiales, *Trebouxia*

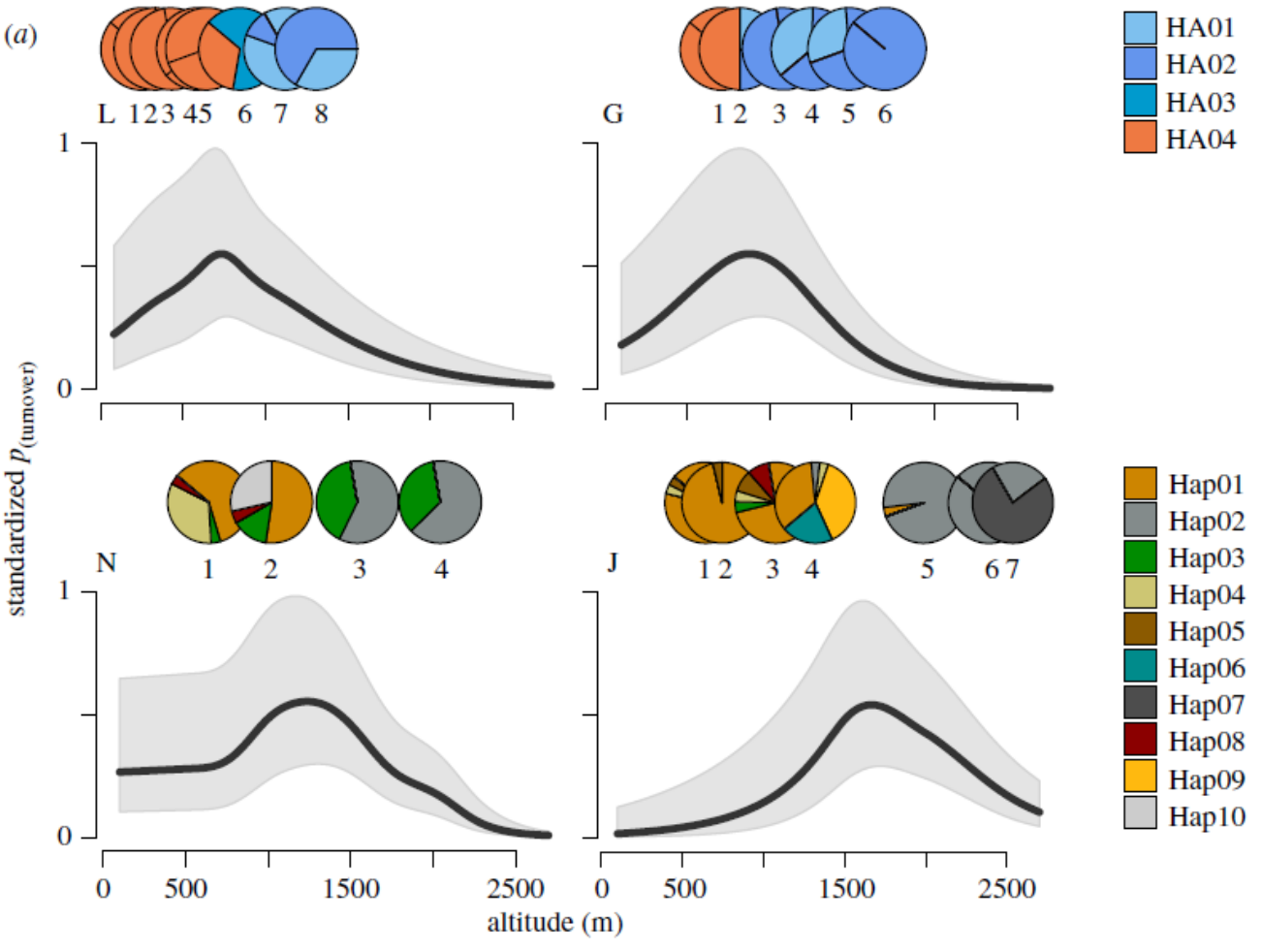
Del Grande et al (2017) – *Lasallia* photobionts – ecological differentiation, host specificity





Trebouxiales, *Trebouxia*

Rolshusen et al (2020) – symbiont turnover zones



Trebouxiales, *Asterochloris*

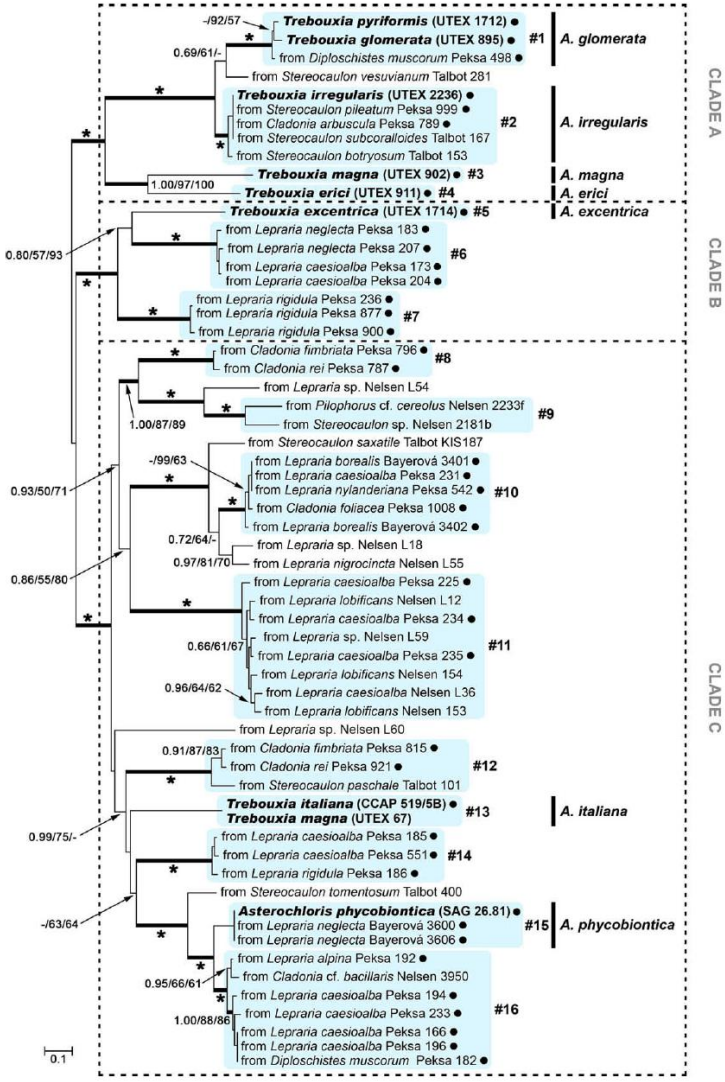


Fig. 3. Unrooted BI analysis based on the combined ITS + actin dataset using a GTR+Γ model for ITS1, K80+I+Γ model for ITS2, and JC model for 5.8 rRNA partition; and HKY+Γ model for the actin-intron 206, HKY+I model for the actin-intron 248, and K80+CP_{123}+I model for the actin-exon partition. The doublet model is applied for the ster regions in all ITS rDNA partitions. Values at the nodes indicate statistical support estimated by three methods – MrBayes posterior node probability (left), maximur likelihood bootstrap (in the middle) and maximum parsimony bootstrap (right). Full statistical support (1.00/100/100) is marked with an asterisk. Thick branches represer nodes receiving the highest PP support (1.00). Sequences determined in this study are marked by full circles. Authentic strains of *Asterochloris phycobiontica* and severa former *Trebouxia* species are given in bold. Strain affiliation to 16 lineages (#1–16) and three major clades (A–C) is indicated. Scale bar – substitutions per site.

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Evolutionary inferences based on ITS rDNA and actin sequences reveal extensive diversity of the common lichen alga *Asterochloris* (Trebouxiophyceae, Chlorophyta)

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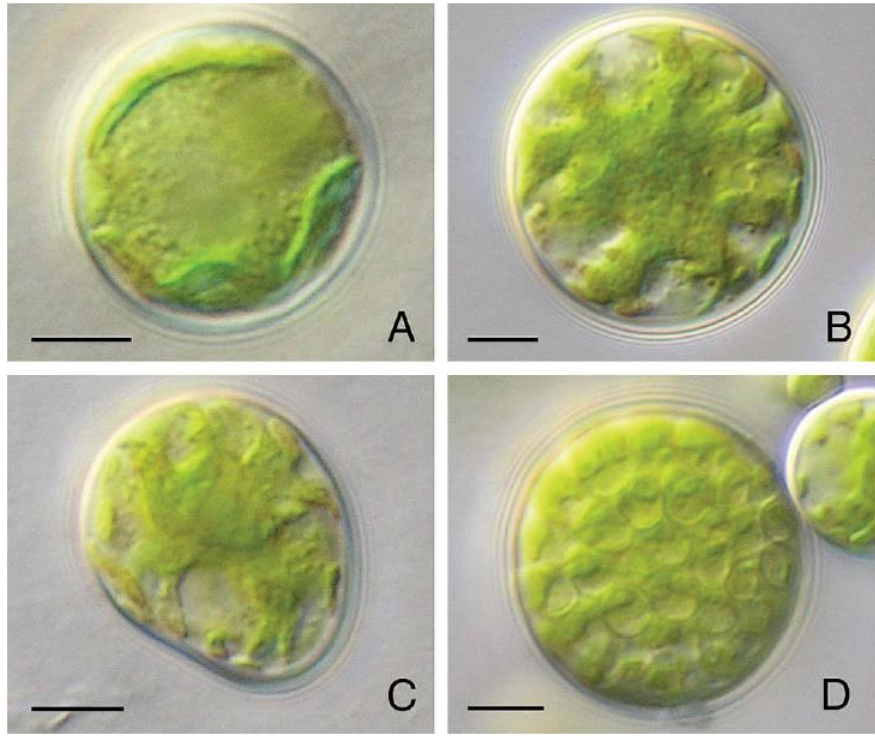
[b] The West Bohemian Museum in Pilsen, Kopeckého sady 2, CZ-30100 Plzeň, Czech Republic



Trebouxiales, *Asterochloris*

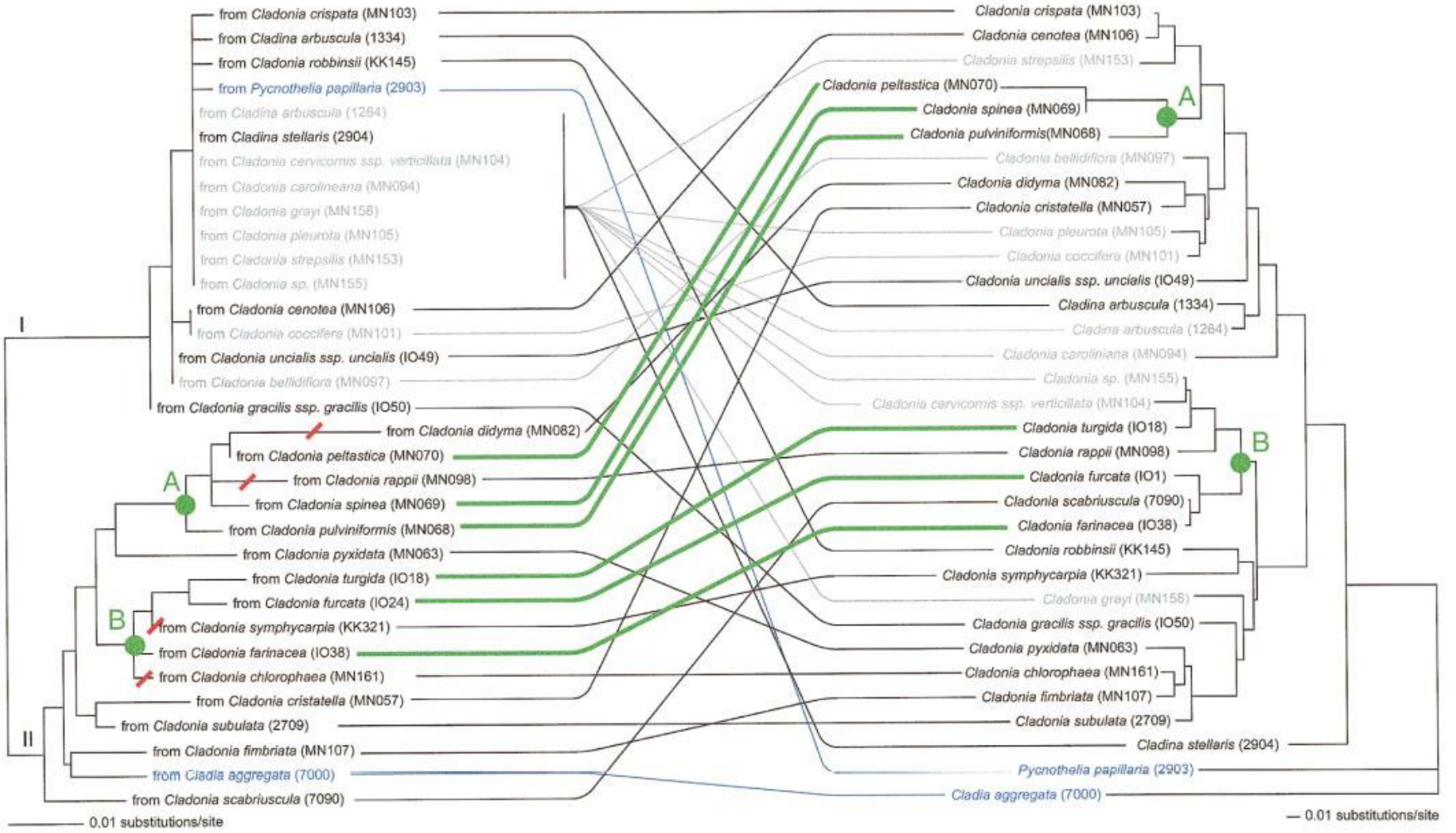
Trebouxiales, *Asterochloris*

American Journal of Botany 88(8): 1490–1498. 2001.

ALGAL SWITCHING AMONG LICHEN SYMBIOSES[1]

MICHELE D. PIERCEY-NORMORE[2] AND PAULA T. DEPRIEST

- incongruent evolution of algae and fungi
- algal domestication



Trebouxiales, *Asterochloris*

MOLECULAR ECOLOGY

Molecular Ecology (2011) **20**, 3936–3948 doi: 10.1111/j.1365-294X.2011.05168.x

Do photobionts influence the ecology of lichens? A case study of environmental preferences in symbiotic green alga *Asterochloris* (Trebouxiophyceae)

ONDŘEJ PEKSA*† and PAVEL ŠKALOUD†

*The West Bohemian Museum in Pilsen, Kopeckého sady 2, CZ-30100 Plzeň, Czech Republic, †Department of Botany, Faculty of Science, Charles University in Prague, Benátská 2, CZ-12801 Prague, Czech Republic

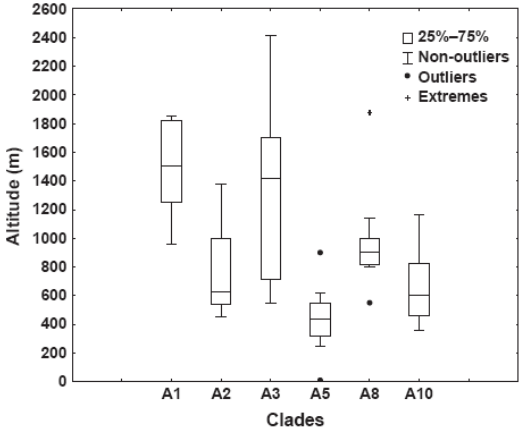


Fig. 3 Differences in the distribution of selected *Asterochloris* clades along the altitudinal gradient. Box and whisker plots are based on altitudinal data from six clades (only those represented by at least eight samples). All samples were collected in similar latitudes in Europe (43–58°N, i.e. somewhere in the temperate belt). The approximate upper borders of vertical vegetation belts for central Europe are as follows: 200 m a.s.l.—lowland, 600 m—colline, 1000 m—submontane, 1400 m—montane, 1800 m—subalpine, 2400 m—alpine.

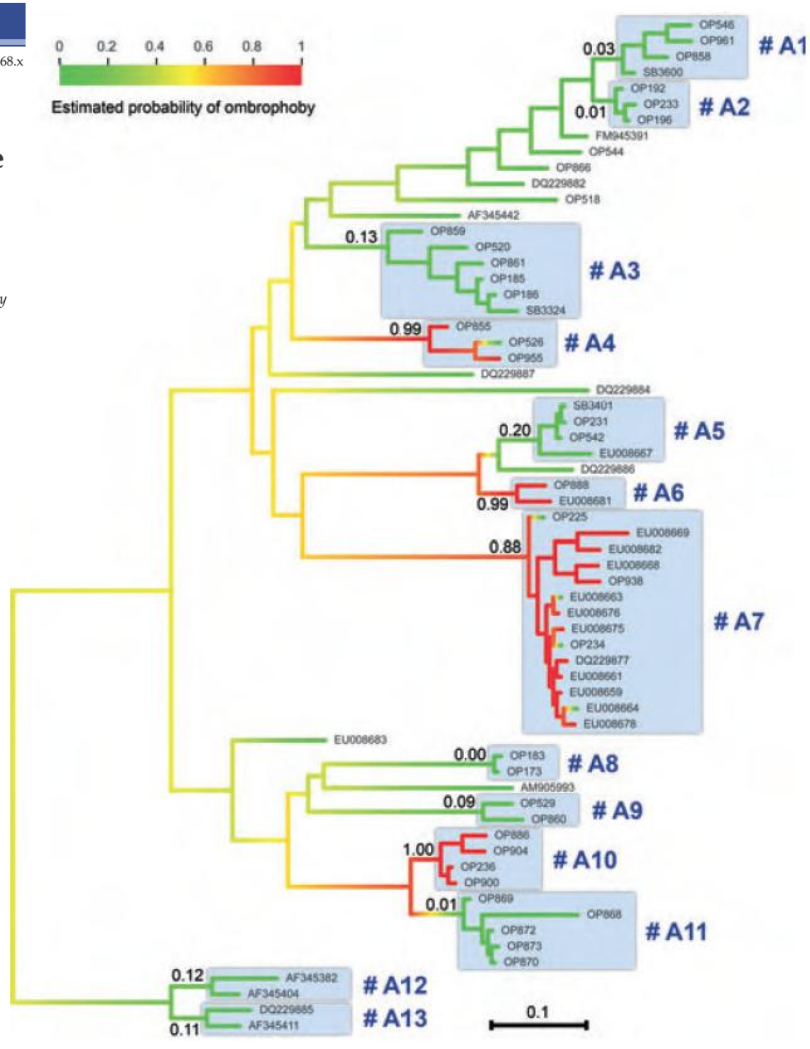
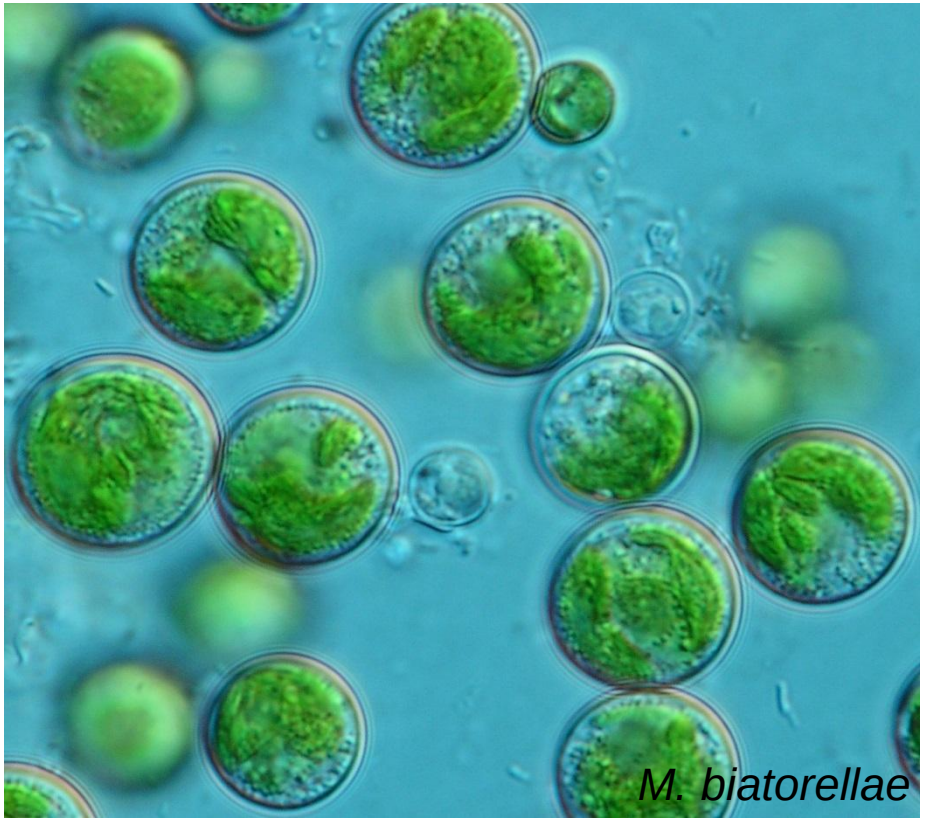


Fig. 2 The evolution of the selected ecological character—the ombrophoby (ombrophily) of lichens—mapped onto the photobiont phylogenetic tree. Colours are used to visualize estimated probabilities of the presence of ombrophoby along the phylogenetic tree. Red indicates a high probability of ombrophoby, whereas green denotes a low probability of ombrophobic preference. The estimated probabilities for ombrophoby are indicated for ancestors of each significantly supported clade (see Fig. 1). The topology of the tree corresponds completely to the topology of the phylogenetic tree in Fig. 1.

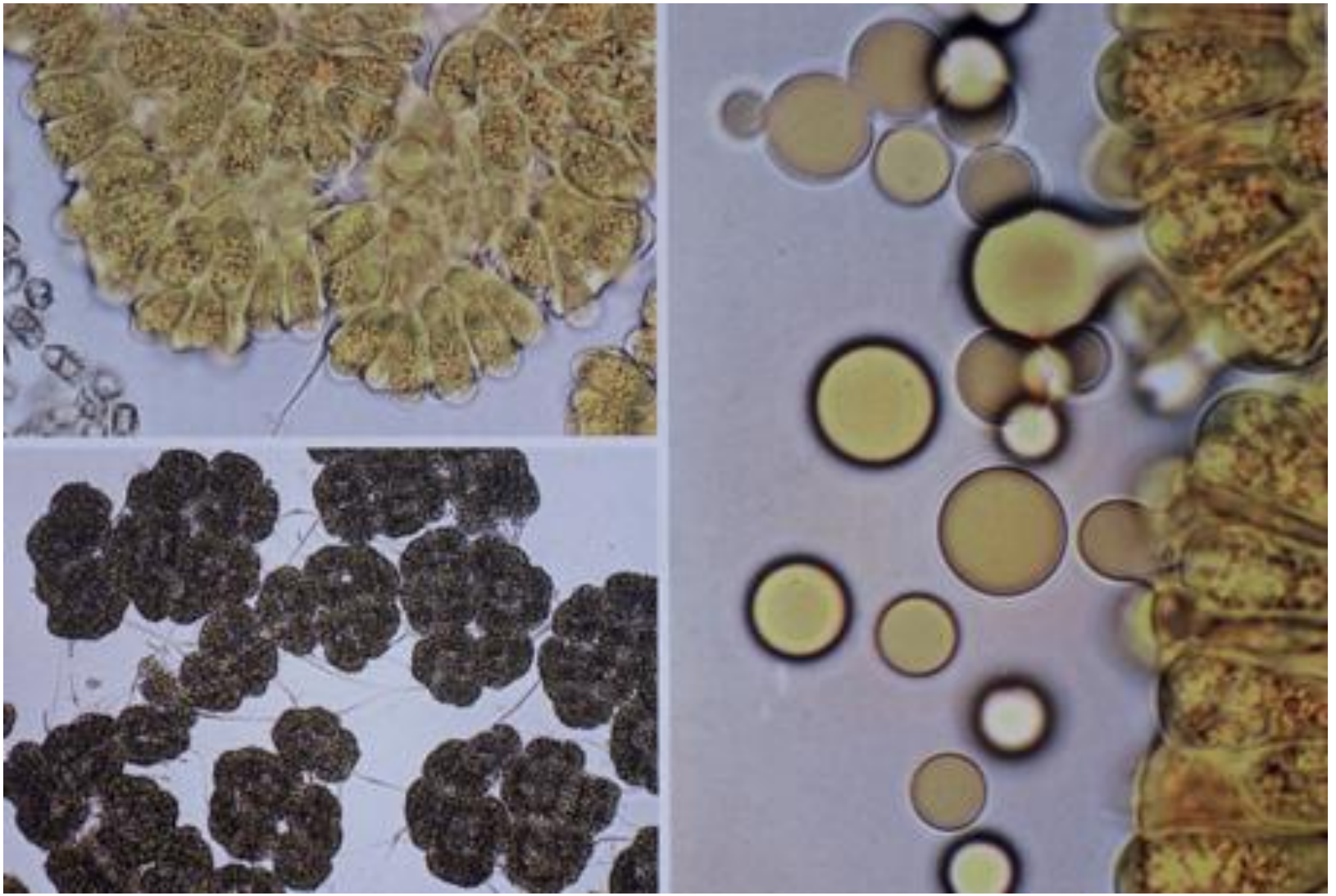
Trebouxiales, *Myrmecia*

- terrestrial, aerophytic
- lichen symbiont



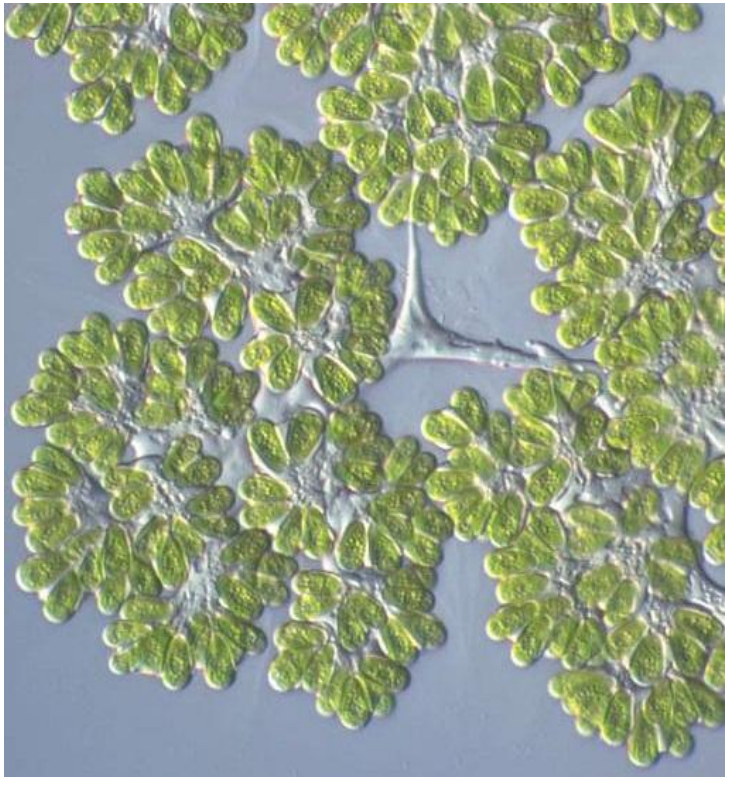
Botryococcus-clade, *Botryococcus*

- *Botryococcus braunii* – colonial green alga

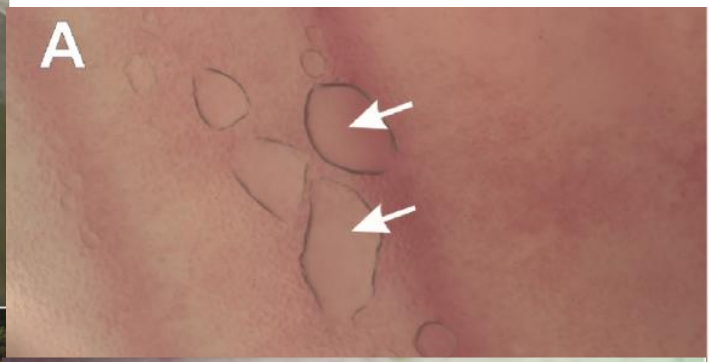


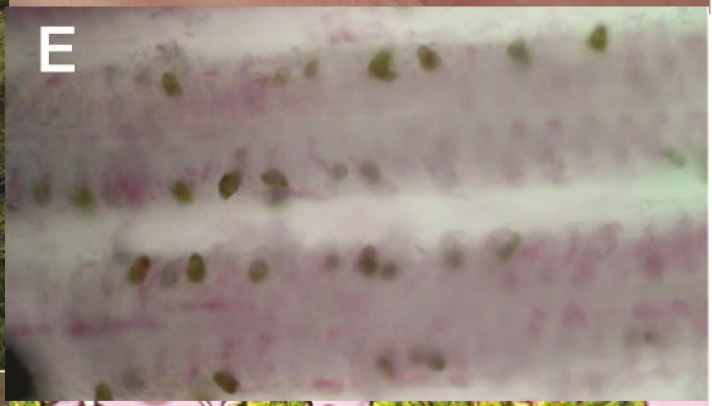
Botryococcus-clade, *Botryococcus*

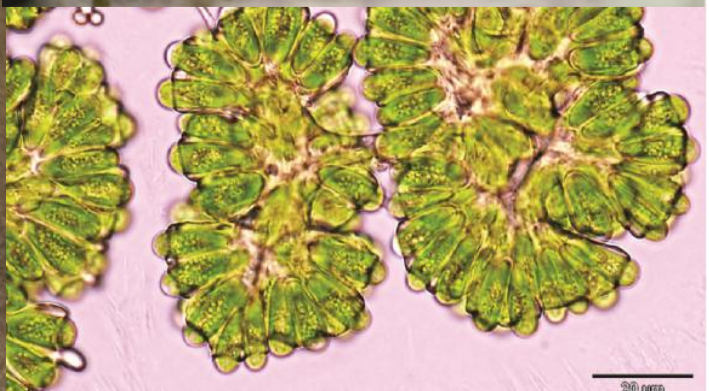
- water blooms
- botryococcen = hydrocarbon, 35% of the dry weight
- fuel?



- fish mortality
- oily droplets in the fish gills

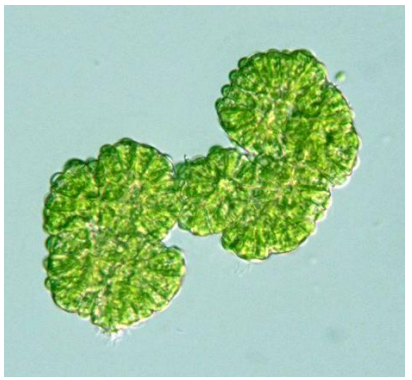


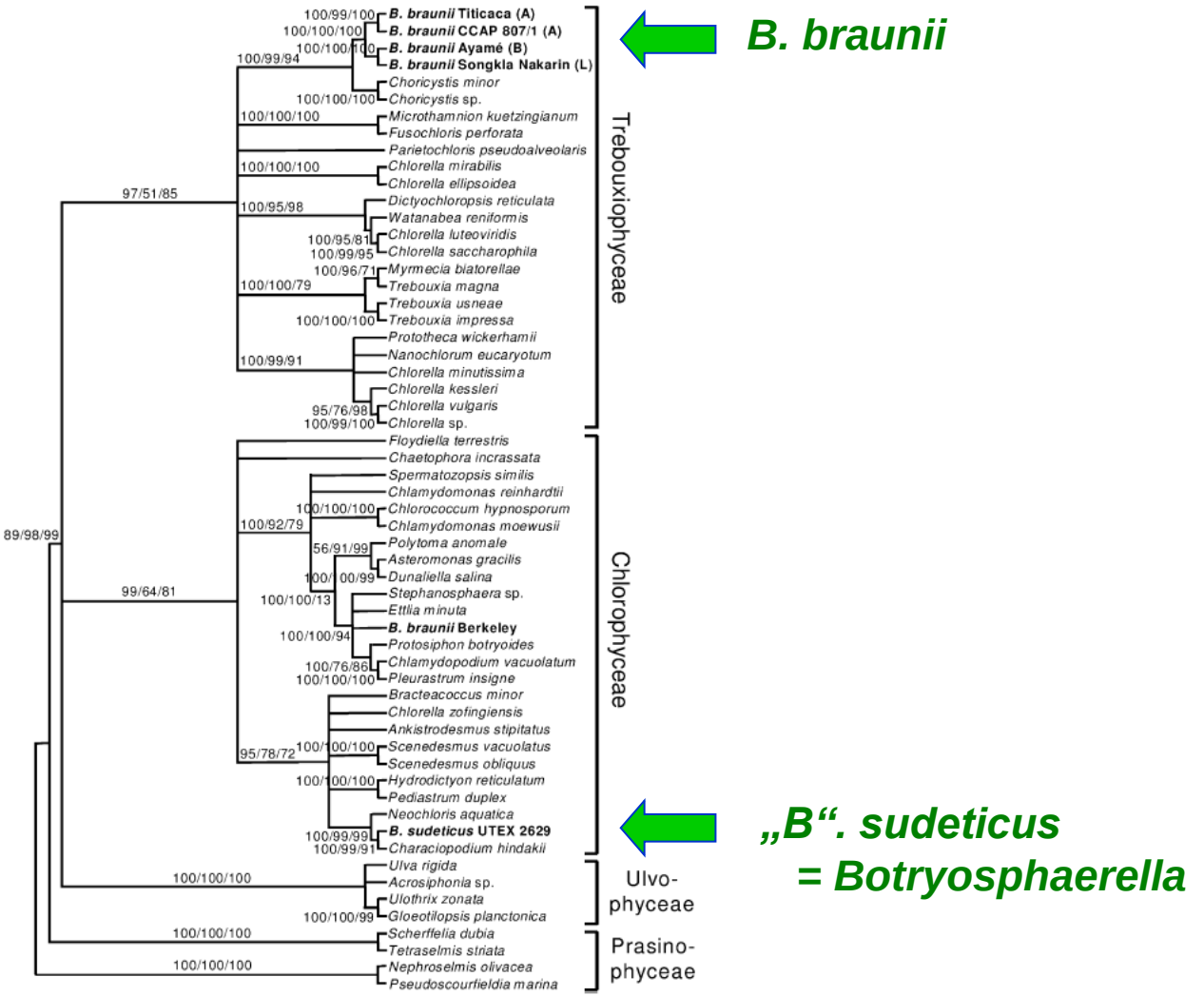




Botryococcus-clade, *Botryococcus*

- Senousy et al. (2004) – polyphyletic *Botryococcus*





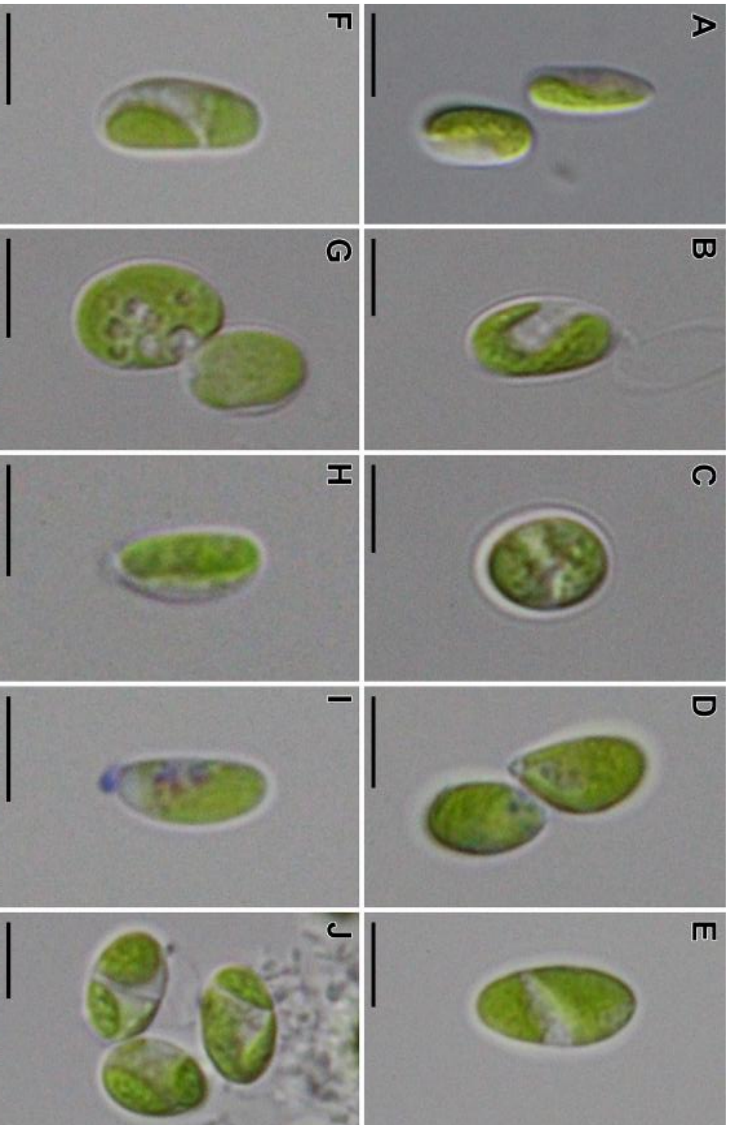
B. braunii

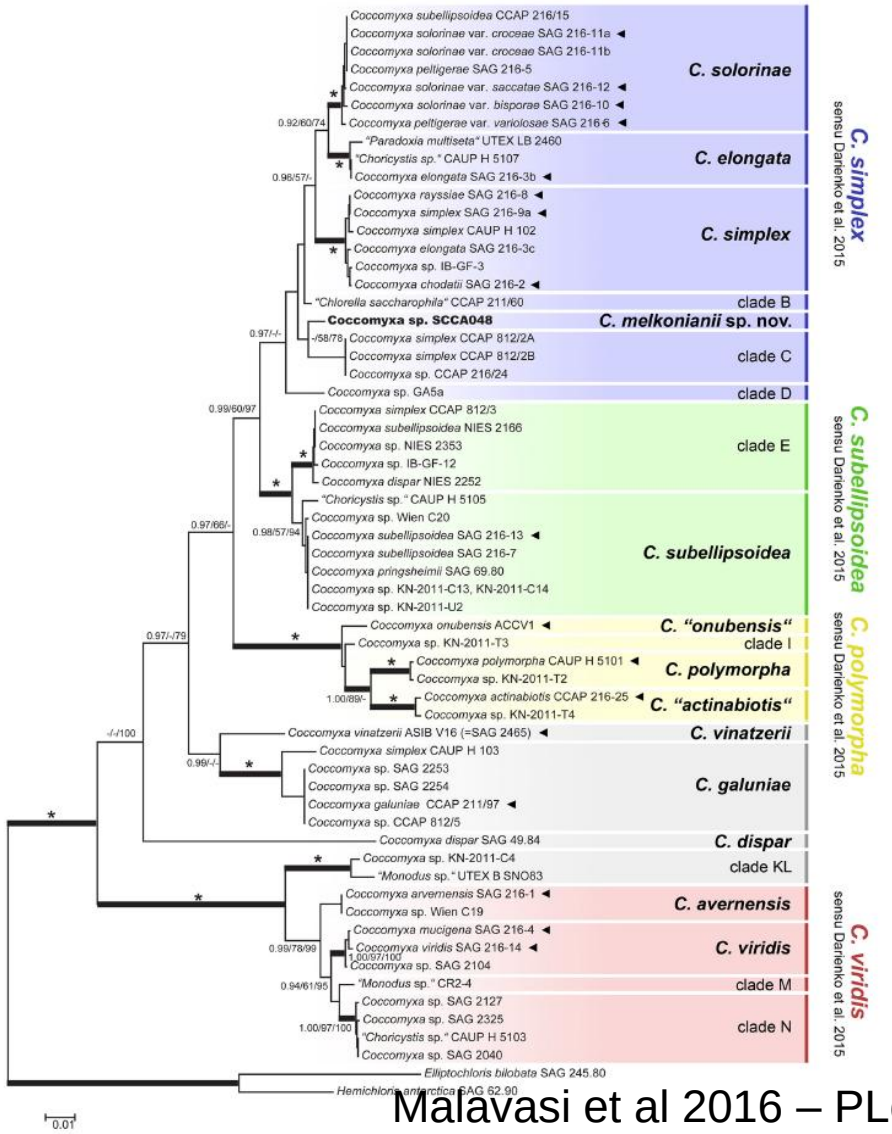
„B“. sudeticus = Botryosphaerella

FIG. 3. Consensus tree from trees inferred with different methods of analysis. The numbers shown at the branches are credibility percentages determined using Bayesian inference (left) and bootstrap values determined using weighted parsimony (middle) and minimum evolution (right). Taxa shown in bold letters are the isolates whose 18S rRNA sequences were determined in this study.

Botryococcus-clade, *Coccomyxa*

- ellipsoid cells, frequent in aerophytic substrate





Malavasi et al 2016 – PLoS ONE

Botryococcus-clade, *Coccomyxa*

- lichen photobionts

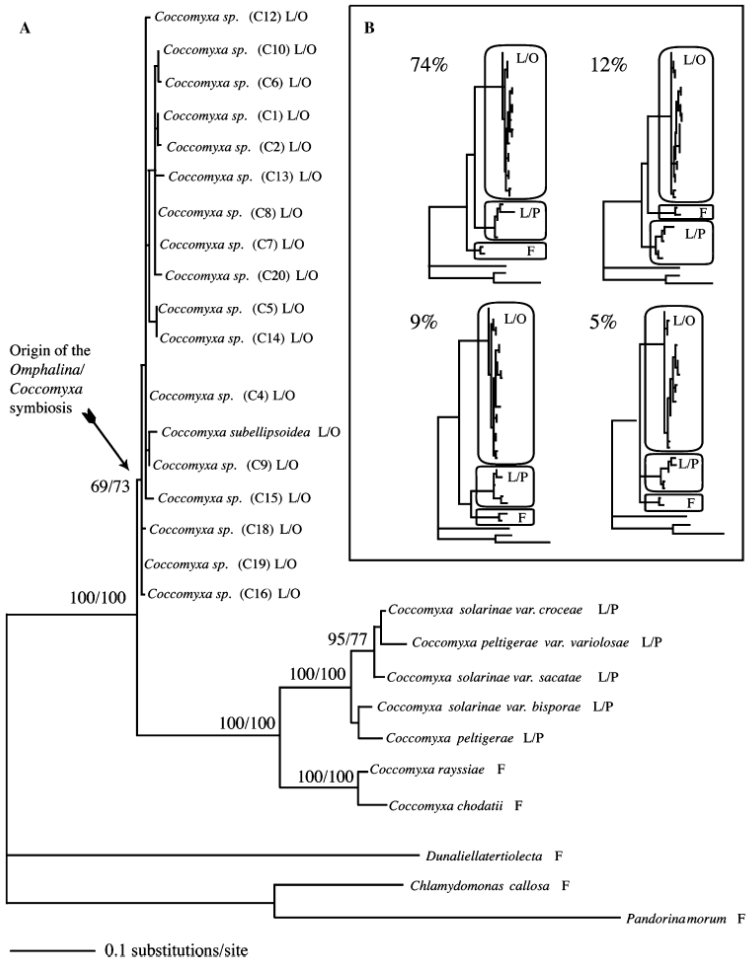


Fig. 3. Phylogenetic relationships among lichenized and non-lichenized *Coccomyxa* algae (dataset AC) as revealed by an ML search using ITS (ITS1-5.8S-ITS2) sequences. *Coccomyxa* isolated from lichenized *Omphalina* species (Basidiomycota) are denoted by a bold L/O after the name. *Coccomyxa* isolated from members of the Peltigerales (Ascomycota) are annotated with a bold L/P. Free-living species are denoted by a bold F. (A) Single most likely tree with maximum parsimony and maximum likelihood bootstrap support values greater than 50% given above internal branches, before and after the backslash, respectively. (B) Frequency of the four topologies recovered by the ML analysis from 100 simulated datasets. The topology under which the data were simulated (monophyly of the lichenized *Coccomyxa* species) was recovered only 74% of the times (top left).

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MOLECULAR PHYLOGENETICS AND EVOLUTION
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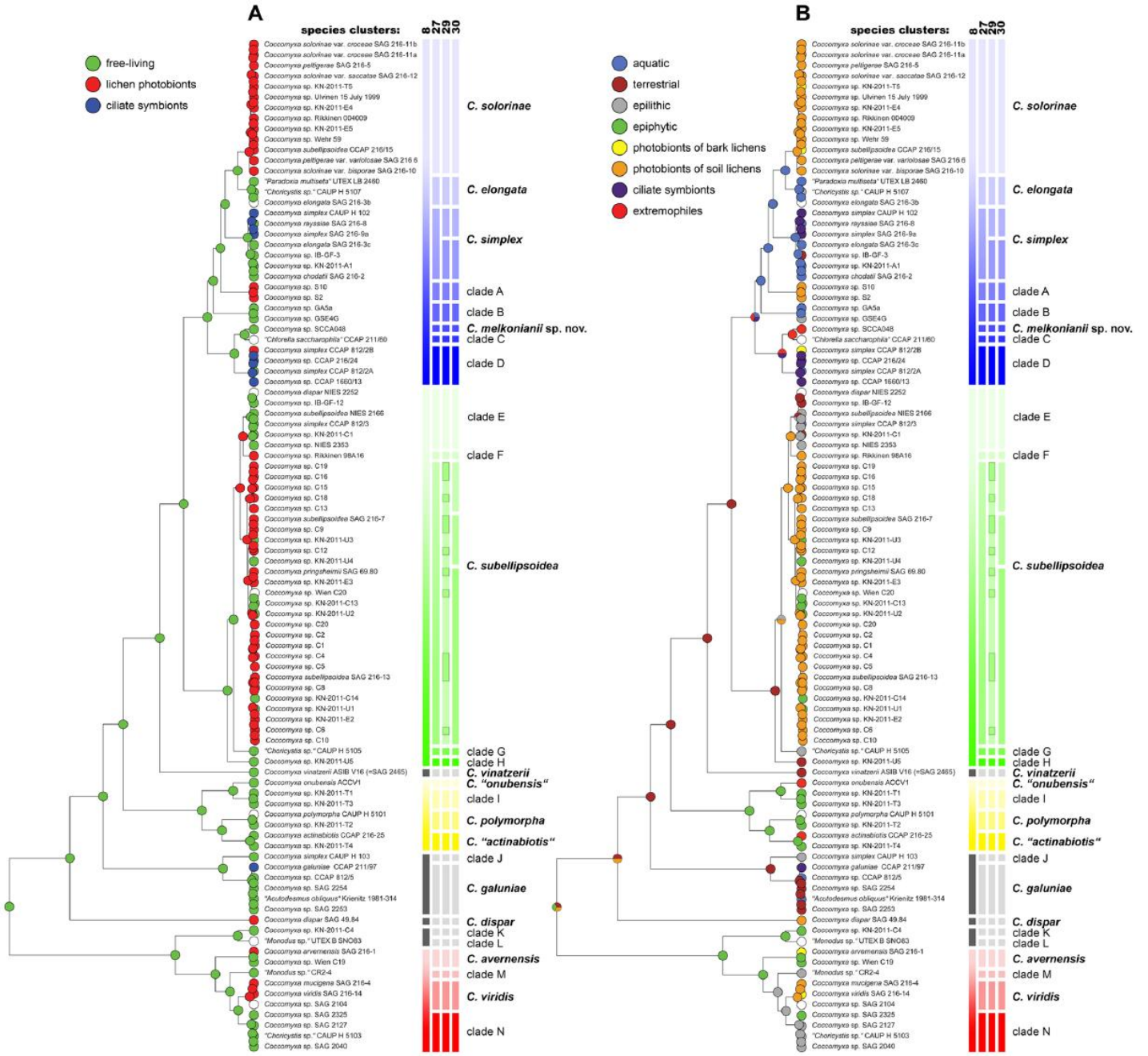
Slow algae, fast fungi: exceptionally high nucleotide substitution rate differences between lichenized fungi *Omphalina* and their symbiotic green algae *Coccomyxa*

Stefan Zoller* and François Lutzoni


A
species clusters:
8
27
29
30
free-living
lichen photobionts
ciliate symbionts
Coccomyxa solorinae var. croceae SAG 216-11b
Coccomyxa solorinae var. croceae SAG 216-11a
Coccomyxa peltigerae SAG 216-5
Coccomyxa solorinae var. saccatae SAG 216-12
Coccomyxa sp. KN-2011-T5
Coccomyxa sp. Ulvinen 15 July 1999
Coccomyxa sp. KN-2011-E4
Coccomyxa sp. Rikkinen 004009
Coccomyxa sp. KN-2011-E5
Coccomyxa sp. Wehr 59
Coccomyxa subellipsoidea CCAP 216/15
Coccomyxa peltigerae var. variolosae SAG 216-6
Coccomyxa solorinae var. bisporae SAG 216-10
"Paradoxia multiseta" UTEX LB 2460
"Choricystis sp." CAUP H 5107
Coccomyxa elongata SAG 216-3b
Coccomyxa simplex CAUP H 102
Coccomyxa reysiae SAG 216-8
Coccomyxa simplex SAG 216-9a
Coccomyxa elongata SAG 216-3c
Coccomyxa sp. IB-GF-3
Coccomyxa sp. KN-2011-A1
Coccomyxa chodatii SAG 216-2
Coccomyxa sp. S10
Coccomyxa sp. S2
Coccomyxa sp. GA5a
Coccomyxa sp. GSE4G
Coccomyxa sp. SCCA048
"Chlorella saccharophila" CCAP 211/80
Coccomyxa simplex CCAP 812/2B
Coccomyxa sp. CCAP 216/24
Coccomyxa simplex CCAP 812/2A
Coccomyxa sp. CCAP 1660/13
Coccomyxa dispar NIES 2252
Coccomyxa sp. IB-GF-12
Coccomyxa subellipsoidea NIES 2166
Coccomyxa simplex CCAP 812/3
Coccomyxa sp. KN-2011-C1
Coccomyxa sp. NIES 2353
Coccomyxa sp. Rikkinen 98A16
Coccomyxa sp. C19
Coccomyxa sp. C16
Coccomyxa sp. C15
Coccomyxa sp. C18
Coccomyxa sp. C13
Coccomyxa subellipsoidea SAG 216-7
Coccomyxa sp. C9
Coccomyxa sp. KN-2011-U3
Coccomyxa sp. C12
Coccomyxa sp. KN-2011-U4
Coccomyxa pringsheimii SAG 69.80
Coccomyxa sp. KN-2011-E3
Coccomyxa sp. Wien C20
Coccomyxa sp. KN-2011-C13
Coccomyxa sp. KN-2011-U2
Coccomyxa sp. C20
Coccomyxa sp. C2
Coccomyxa sp. C1
Coccomyxa sp. C4
Coccomyxa sp. C5
Coccomyxa subellipsoidea SAG 216-13
Coccomyxa sp. C8
Coccomyxa sp. KN-2011-C14
Coccomyxa sp. KN-2011-U1
Coccomyxa sp. KN-2011-E2
Coccomyxa sp. C6
Coccomyxa sp. C10
"Choricystis sp." CAUP H 5105
Coccomyxa sp. KN-2011-U5
Coccomyxa vinatzerii ASIB V16 (=SAG 2465)
Coccomyxa onubensis ACCV1
Coccomyxa sp. KN-2011-T1
Coccomyxa sp. KN-2011-T3
Coccomyxa polymorpha CAUP H 5101
Coccomyxa sp. KN-2011-T2
Coccomyxa actinabiotis CCAP 216-25
Coccomyxa sp. KN-2011-T4
Coccomyxa simplex CAUP H 103
Coccomyxa galuniae CCAP 211/97
Coccomyxa sp. CCAP 812/5
Coccomyxa sp. SAG 2254
"Acutodesmus obliquus" Krienitz 1981-314
Coccomyxa sp. SAG 2253
Coccomyxa dispar SAG 49.84
Coccomyxa sp. KN-2011-C4
"Monodus sp." UTEX B SNG63
Coccomyxa arvernensis SAG 216-1
Coccomyxa sp. Wien C19
"Monodus sp." CR2-4
Coccomyxa mucigena SAG 216-4
Coccomyxa viridis SAG 216-14
Coccomyxa sp. SAG 2104
Coccomyxa sp. SAG 2325
Coccomyxa sp. SAG 2127
"Choricystis sp." CAUP H 5103
Coccomyxa sp. SAG 2040
C. solorinae
C. elongata
C. simplex
clade A
clade B
C. melkonianii sp. nov.
clade C
clade D
clade E
clade F
C. subellipsoidea
clade G
clade H
C. vinatzerii
C. "onubensis"
clade I
C. polymorpha
C. "actinabiotis"
clade J
C. galuniae
C. dispar
clade K
clade L
C. avernensis
clade M
C. viridis
clade N
B
species clusters:
8
27
29
aquatic
terrestrial
epilithic
epiphytic
photobionts of bark lichens
photobionts of soil lichens
ciliate symbionts
extremophiles
C. solorinae
C. elongata
C. simplex
clade A
clade B
C. melkonianii sp. nov.
clade C
clade D
clade E
clade F
C. subellipsoidea
clade G
clade H
C. vinatzerii
C. "onubensis"
clade I
C. polymorpha
C. "actinabiotis"
clade J
C. galuniae
C. dispar
clade K
clade L
C. avernensis
clade M
C. viridis
clade N

Botryococcus-clade, *Coccomyxa*

Vol. 81: 231–240, 2008
doi: 10.3354/dao01956

DISEASES OF AQUATIC ORGANISMS
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Published September 24

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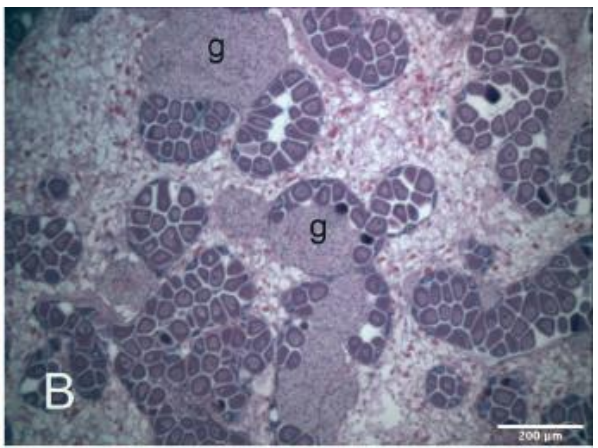
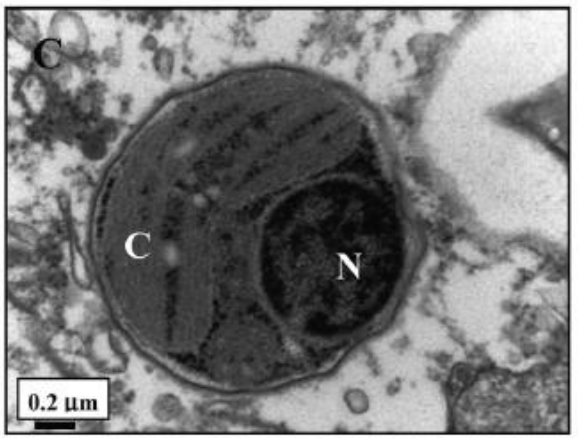
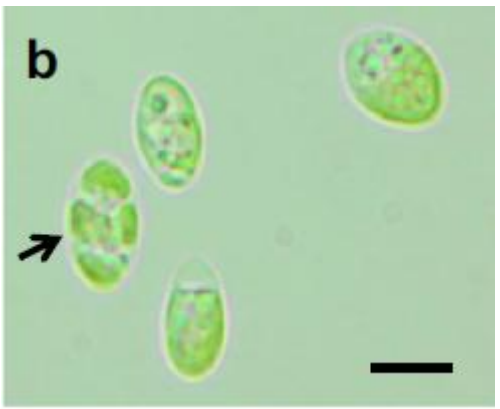
Phylogenetic and morphological characterisation of the green algae infesting blue mussel *Mytilus edulis* in the North and South Atlantic oceans

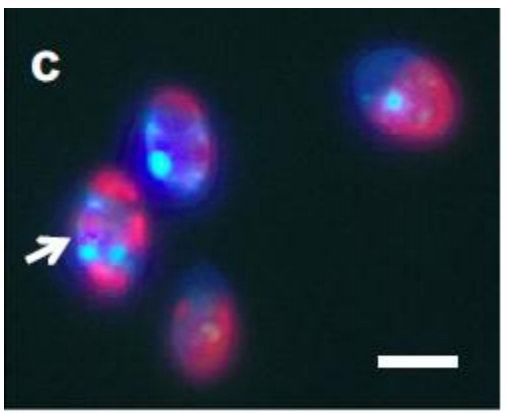
Francisco Rodríguez[1,5], Stephen W. Feist[2], Laure Guillou[1], Lisbeth S. Harkestad[3], Kelly Bateman[2], Tristan Renault[4], Stein Mortensen[3,*]





Botryococcus-clade, *Coccomyxa*





- *C. actinabiotis*

An extremely radioresistant green eukaryote for radionuclide bio-decontamination in the nuclear industry

Corinne Rivasseau,[*abcd] Emmanuel Farhi,[*e] Ariane Atteia,[f] Alain Couté,[g] Marina Gromova,[h] Diane de Gouvion Saint Cyr,[abcde] Anne-Marie Boisson,[abcd] Anne-Sophie Féret,[abcd] Estelle Compagnon[e] and Richard Bligny[abcd]

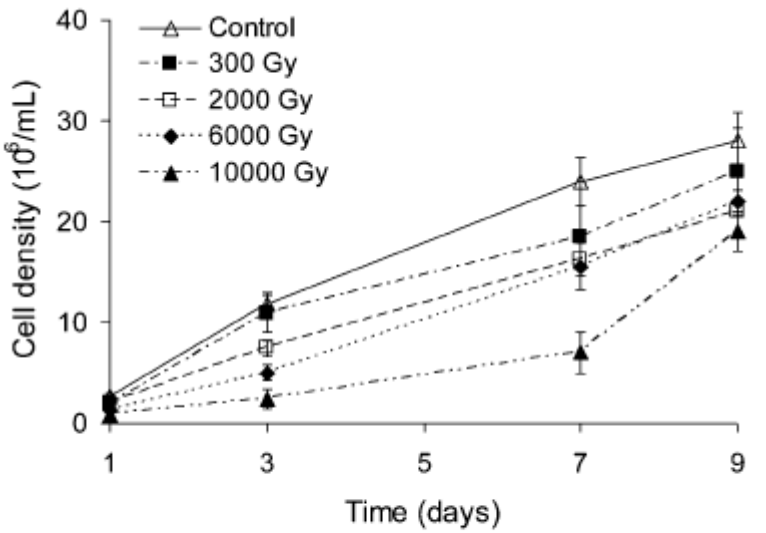
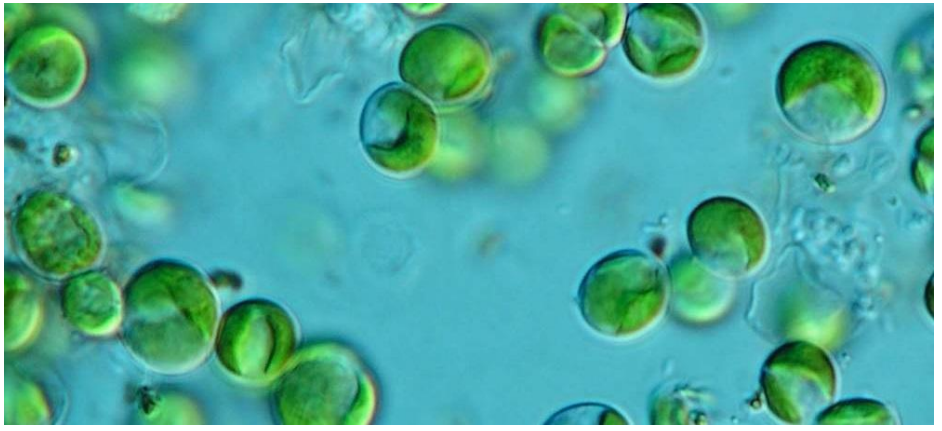
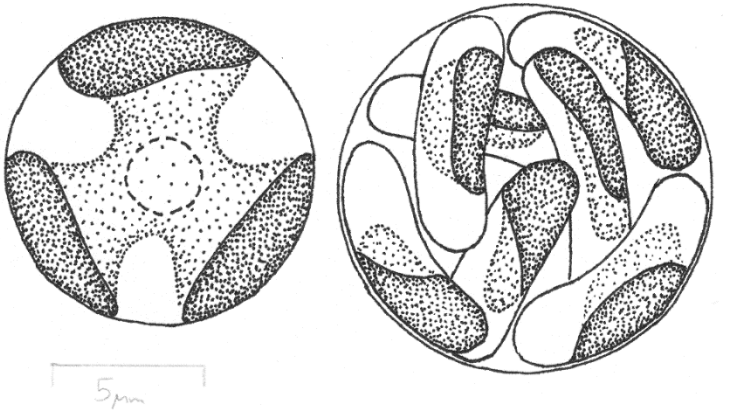


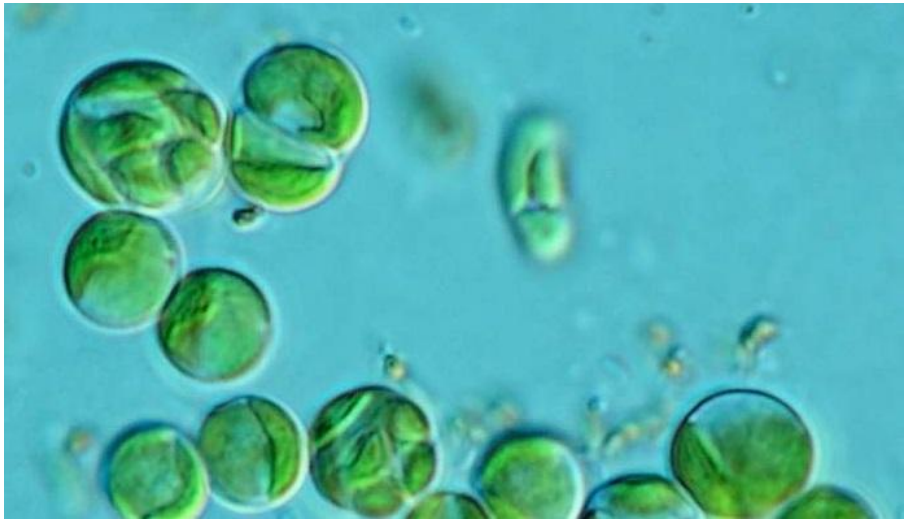
Fig. 3 Growth of *C. actinabiotis* after acute γ-irradiation at 300, 2000, 6000, and 10 000 Gy. Values are average of triplicate experiments ± standard deviation.

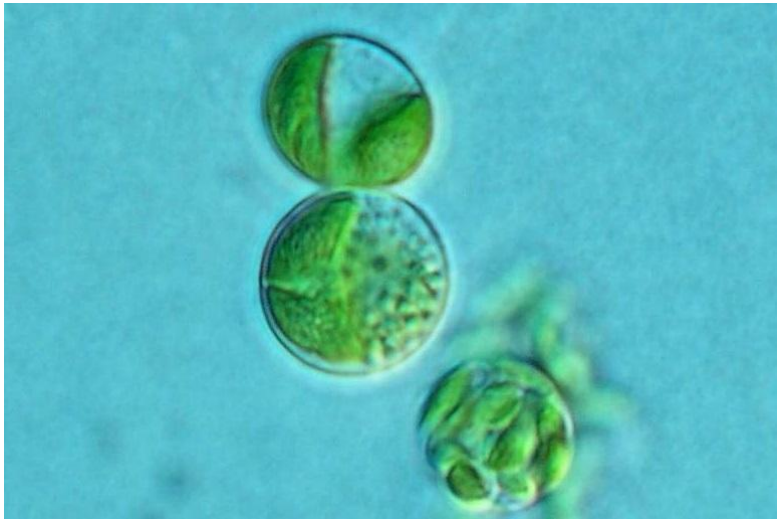
Botryococcus-clade, *Elliptochloris*

- 2 autospore types







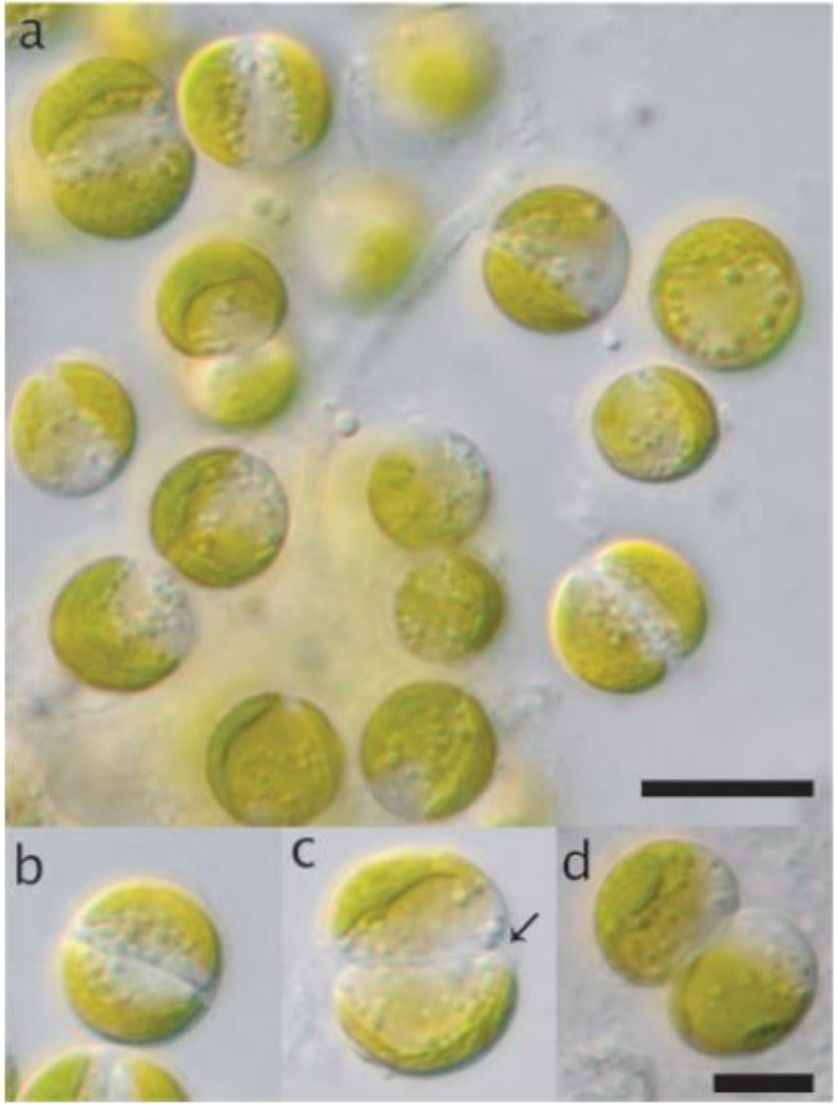


Botryococcus-clade, *Elliptochloris*

- symbiont of lichens (*Baeomyces*, *Catolechia*), sea anemones (*Anthopleura*)

Botryococcus-clade, *Elliptochloris*

- symbiont of lichens (*Baeomyces*, *Catolechia*), sea anemones (*Anthopleura*)



J. Phycol. **45,** 1127–1135 (2009)

DOI: 10.1111/j.1529-8817.2009.00727.x

ELLIPTOCHLORIS MARINA SP. NOV. (TREBOUXIOPHYCEAE, CHLOROPHYTA), SYMBIOTIC GREEN ALGA OF THE TEMPERATE PACIFIC SEA ANEMONES *ANTHOPLEURA XANTHOGRAMMICA* AND *A. ELEGANTISSIMA* (ANTHOZOA, CNIDARIA)[1]

Molly R. Letsch[2]

Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, Connecticut 06269, USA

Gisèle Muller-Parker

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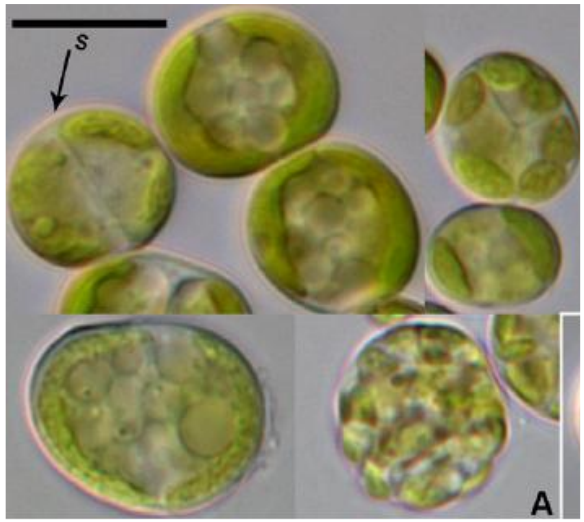
Thomas Friedl

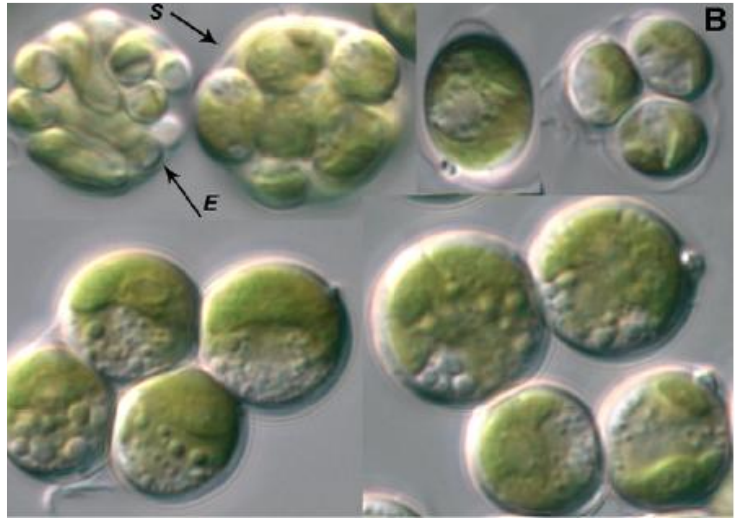
Experimental Phycology and Culture Collection of Algae, Georg-August University Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

and Louise A. Lewis

Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, Connecticut 06269, USA

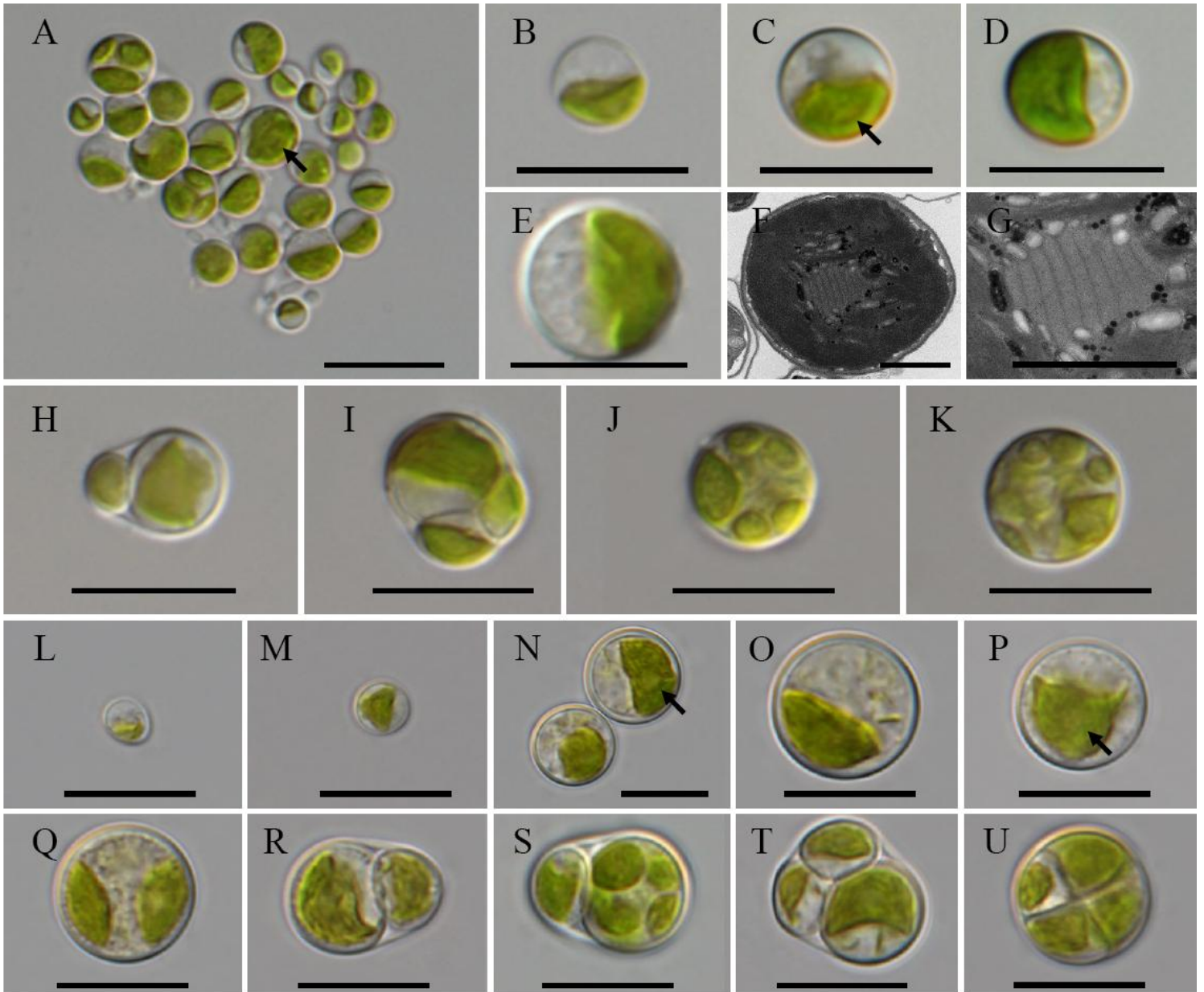
Elliptochloris, *Pseudochlorella*

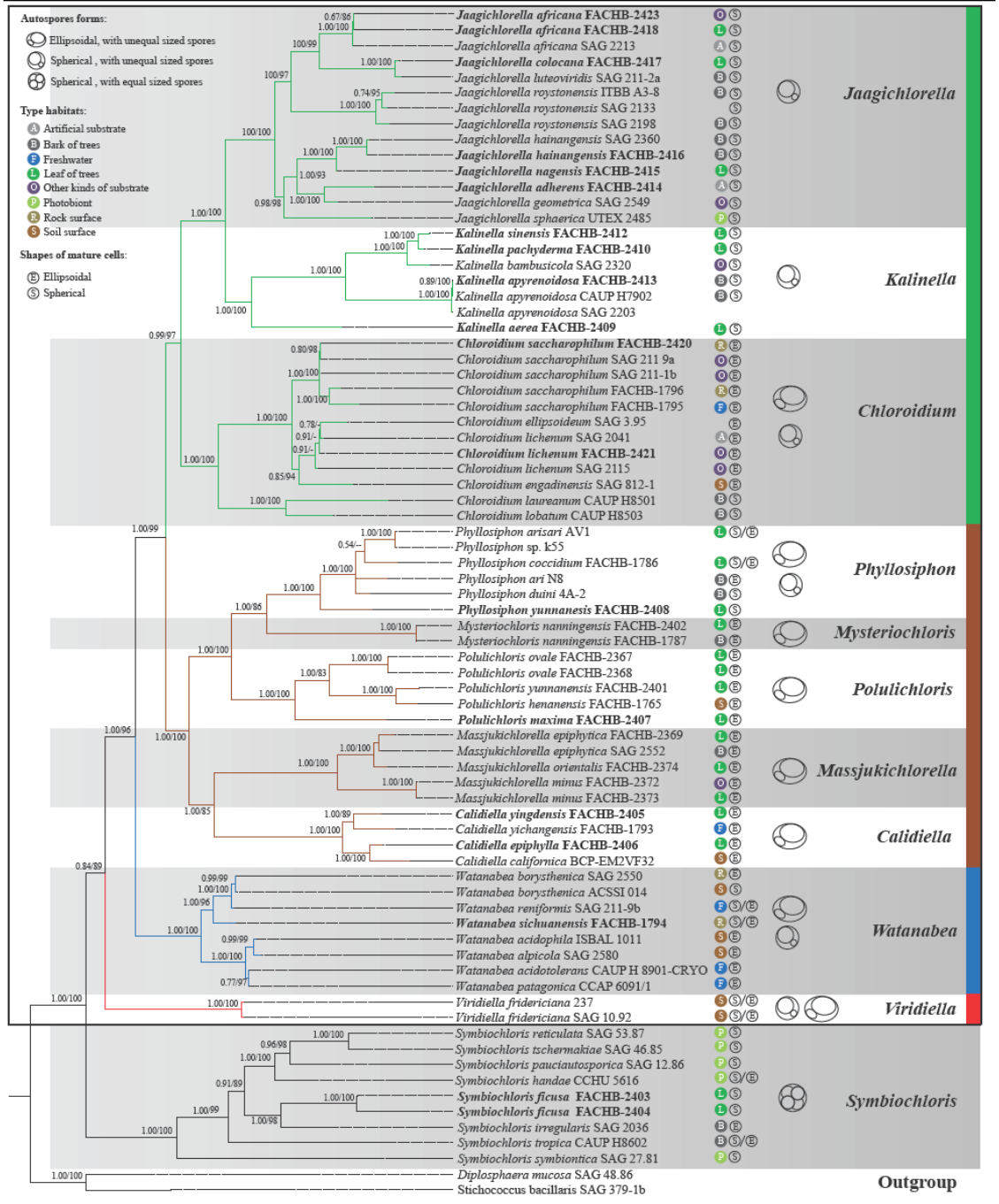




Darienko et al. (2016): J Phycol 52, 1125-1145

Watanabeales

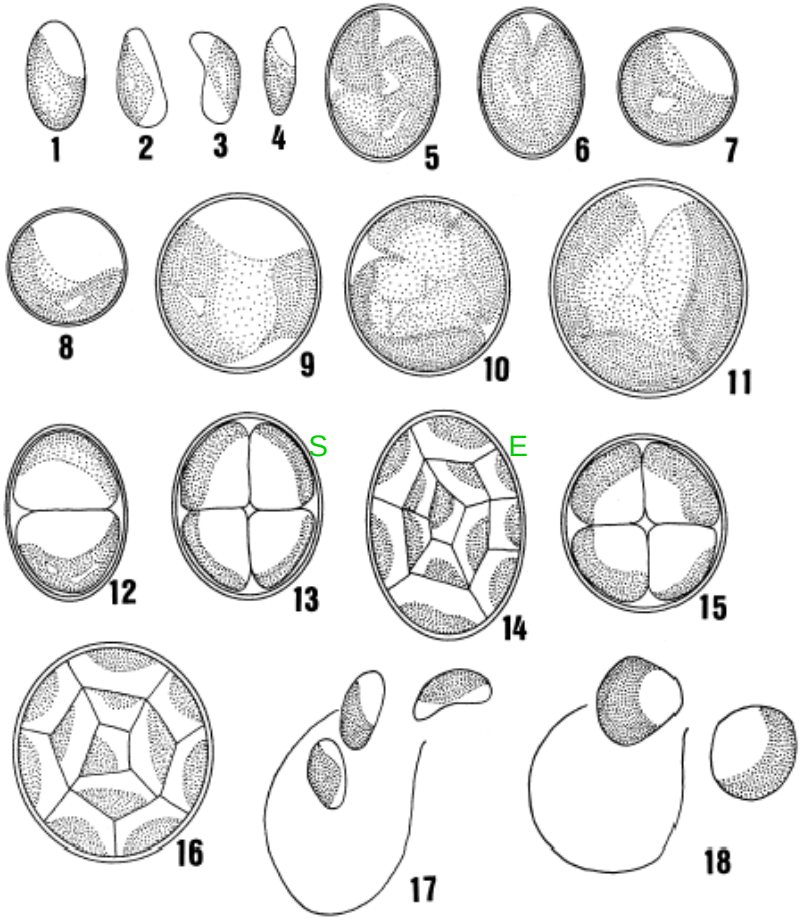


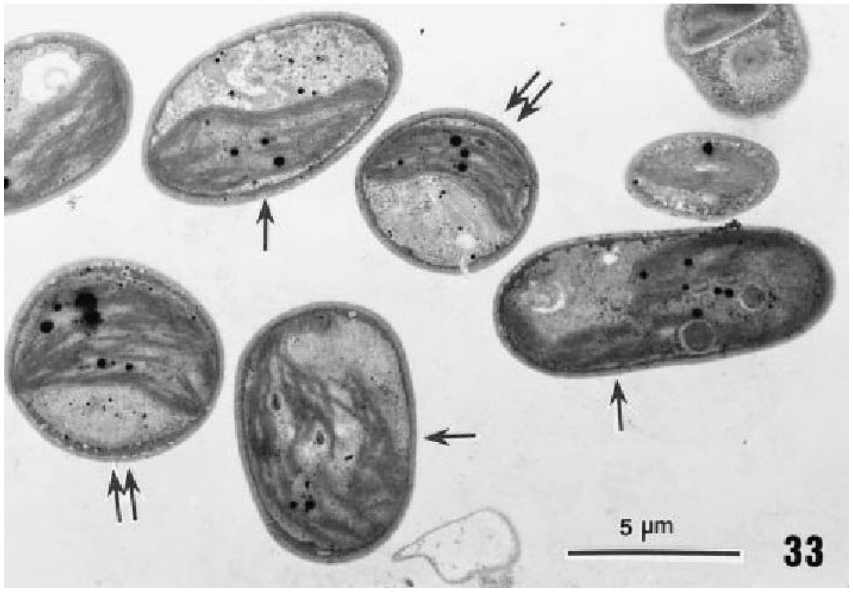


Li et al. (2021): J Phycol

Watanabeales, *Watanabea*

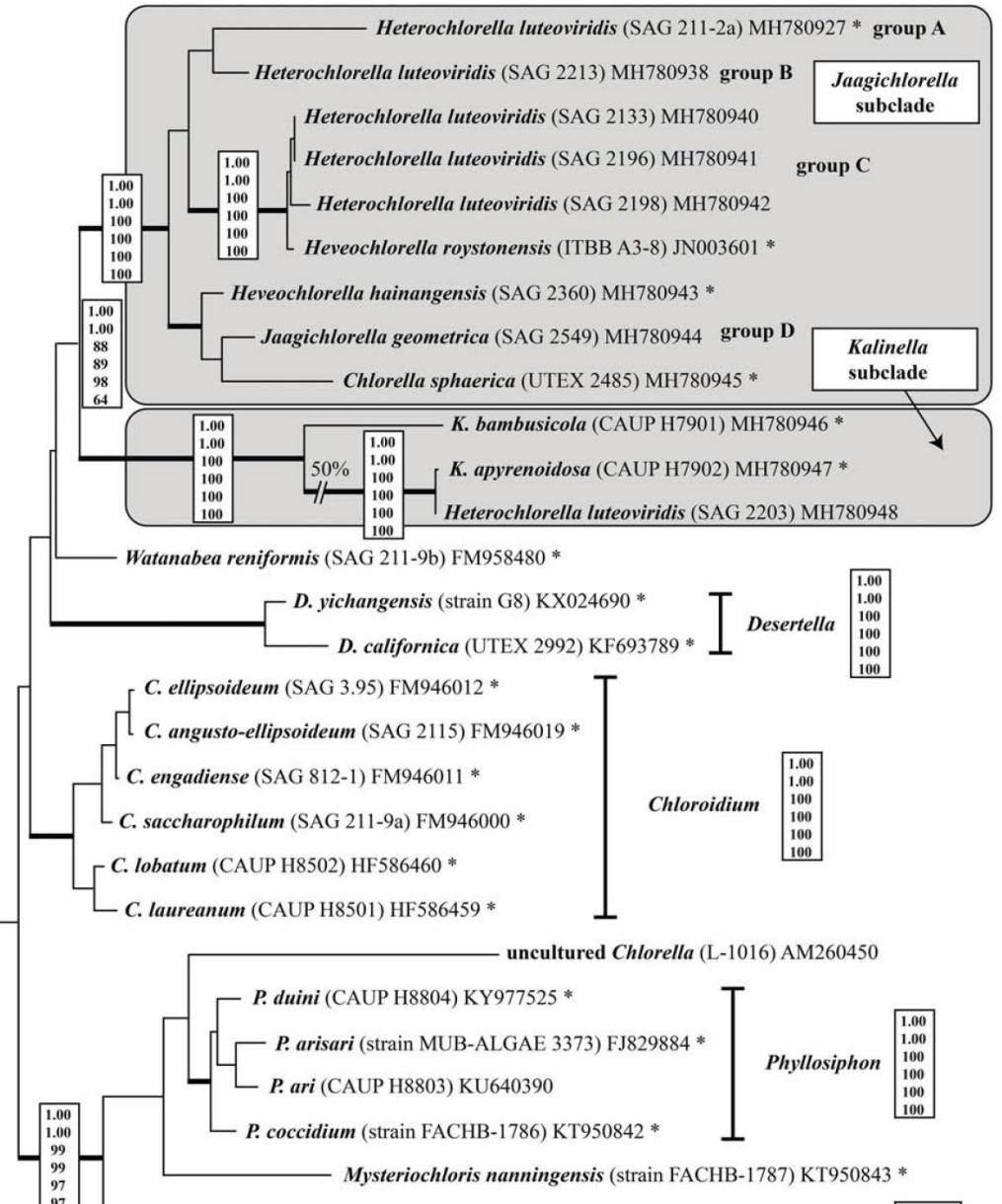
- *W. reniformis* (Hanagata et al., 1998) – 2 autospore types
- characteristic cell wall (different from *Elliptochloris*)

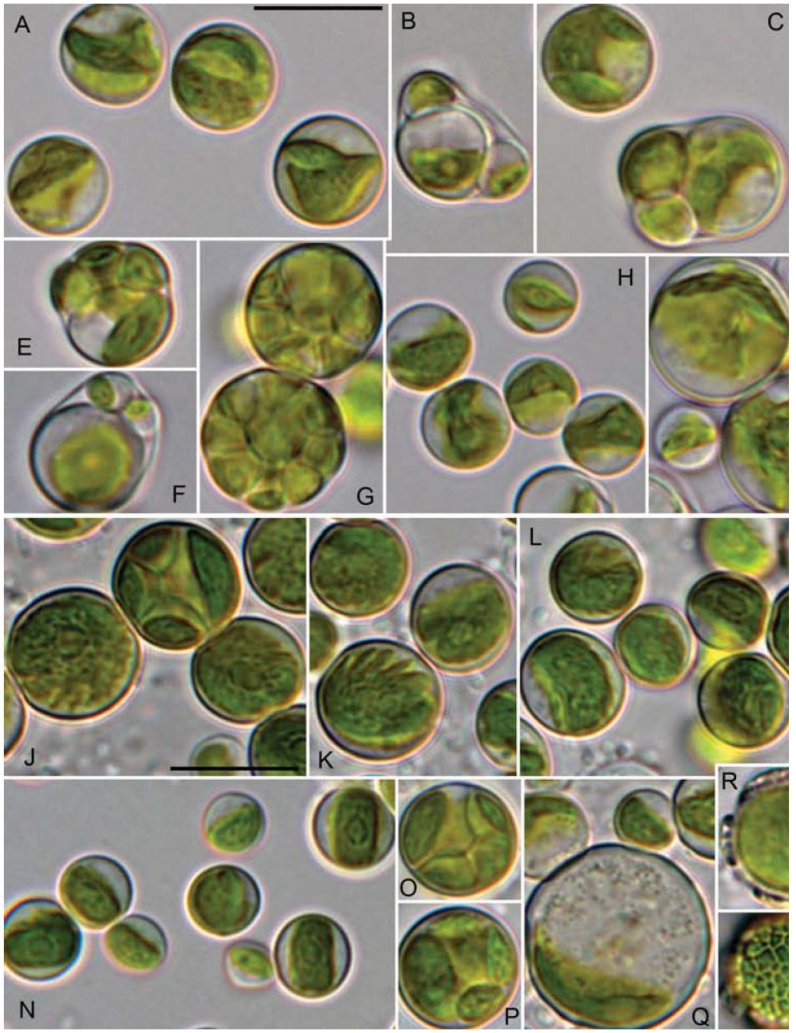




- unilayered CW (*Elliptochloris* – trilaminar CW)

Watanabeales, *Jaagichlorella*





Darienko & Pröschold 2019

Watanabeales, *Chloroidium*

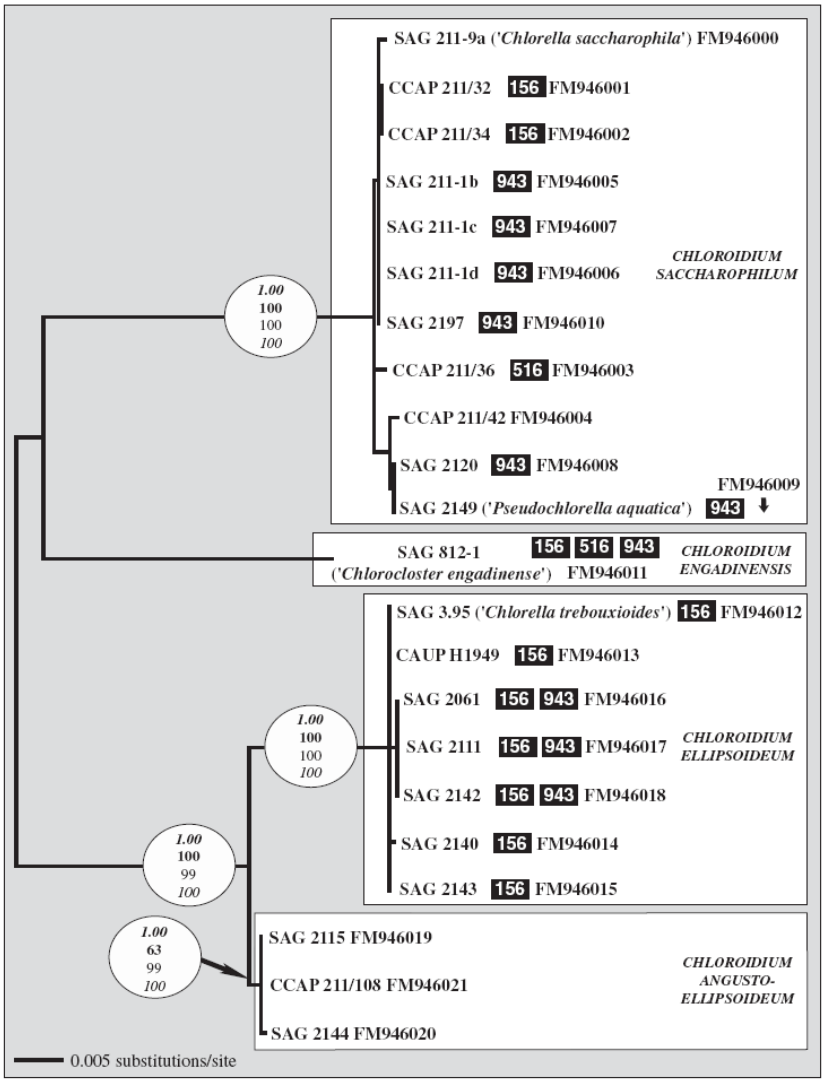


Fig. 2. Molecular phylogeny of *Chloroidium* based on SSU and ITS rDNA sequences, inferred by maximum likelihood (ML) based on a data set of 2500 aligned positions of 22 taxa using PAUP 4.0b10, using GTR model, with proportion of invariable sites I = 0.86. Bayesian values (>0.95; bold italic) using the covarion model (5 million generations) and bootstrap values (>50%) of the ML (using the GTR + I model, 100 replicates; bold), neighbor-joining (using the GTR + I model, 1000 replicates; not bold), and maximum parsimony (1000 replicates; italic) are shown in boxes on the tree. Strains marked in bold are new sequences, and strain and accession numbers, as well as intron position (white number in black box), are given.

Eur. J. Phycol., 2010, 1–17, iFirst

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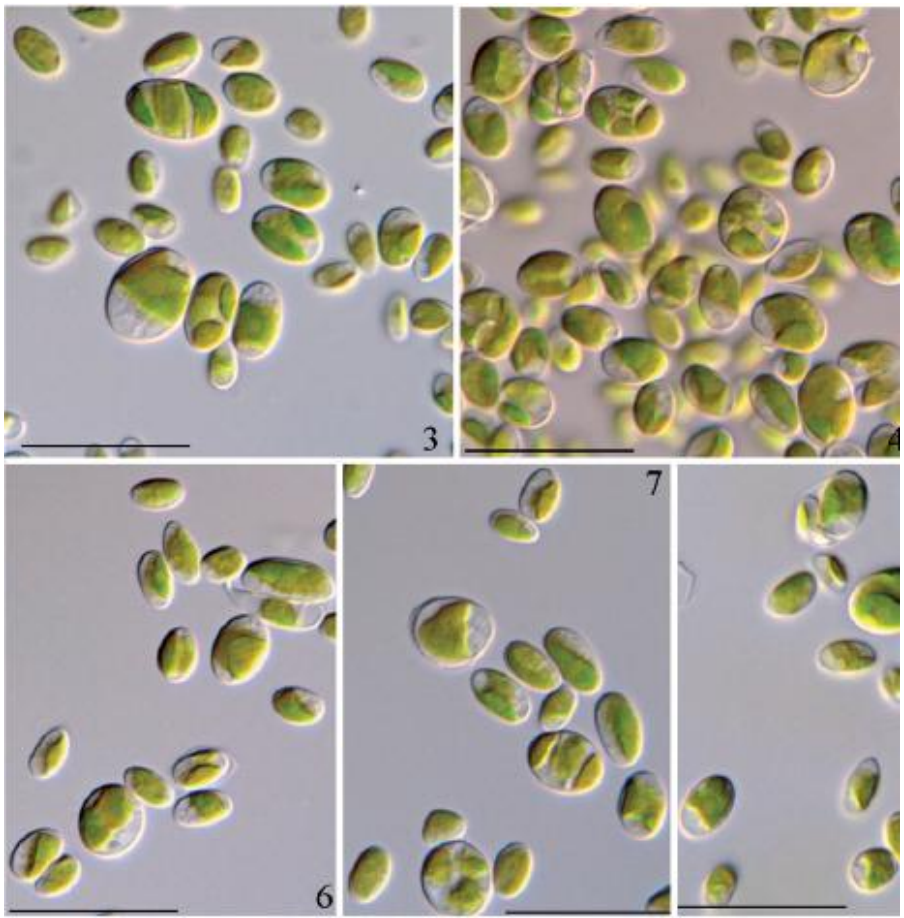
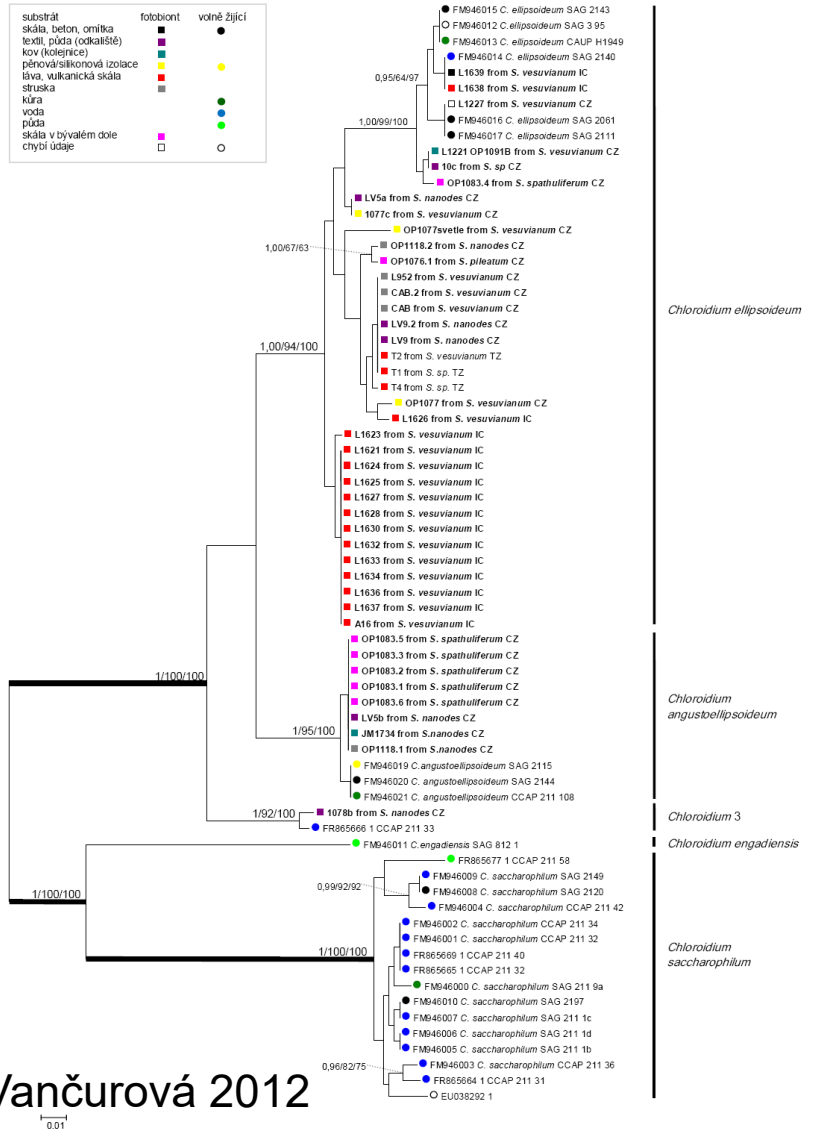
Chloroidium, a common terrestrial coccoid green alga previously assigned to *Chlorella* (Trebouxiophyceae, Chlorophyta)

TATYANA DARIENKO[1], LYDIA GUSTAVS[2], OPAYI MUDIMU[3,5], CECILIA RAD MENENDEZ[4], RHENA SCHUMANN[2], ULF KARSTEN[2], THOMAS FRIEDL[3] AND THOMAS PRÖSCHOLD[4]



Watanabeales, *Chloroidium*



Vančurová 2012

Obrázek 15: Nezakořeněný BI fylogenetický strom založený úseku ITS rDNA. Hodnoty v uzlech vyjadřují statistickou podporu určenou třemi metodami: MrBayes posteriorní pravděpodobnost/maximum likelihood bootstrap/maximum parsimony bootstrap. Zobrazeny jsou pouze hodnoty >0,89 pro BI a >49 pro ML/MP. Popisky sekvencí fotobiontů obsahují označení DNA, druh mykobionta a geografický původ (CZ – Česká republika, IC – Kanárské ostrovy, TZ – Tanzánie). Popisky sekvencí volně žijících zástupců obsahují číslo sekvence v GenBanku, druh dle (Darienko et al., 2010) a číslo sbírkového kmene.

Watanabeales, *Phyllosiphon*

- sifonal parasitic alga
- leaves of *Arisarum*

Eur. J. Phycol. (2011) **46(3)**: 181–192

Taylor & Francis
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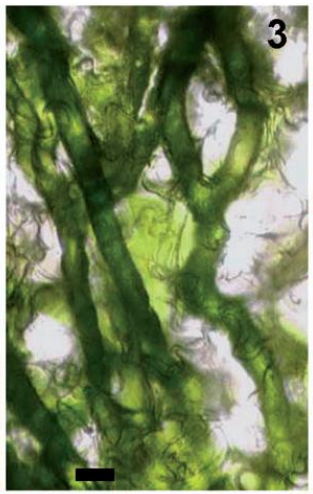
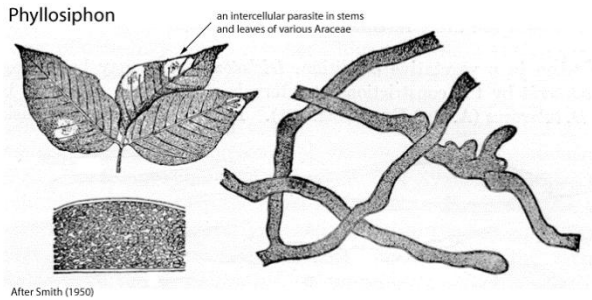
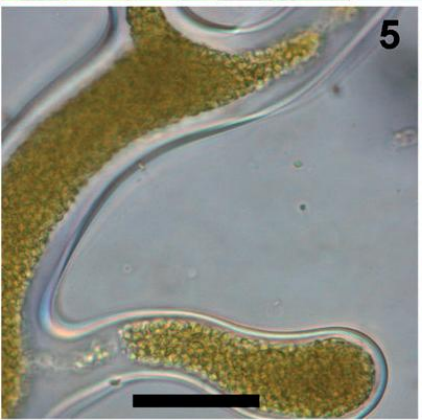
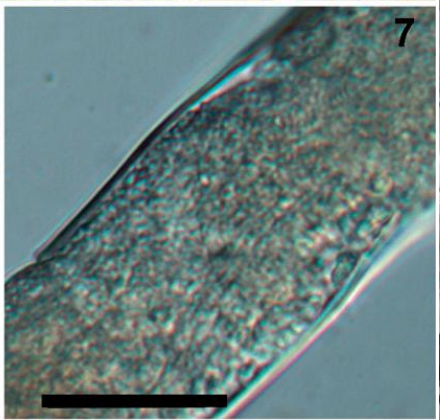
Morphology, fine structure, life cycle and phylogenetic analysis of *Phyllosiphon arisari*, a siphonous parasitic green alga

MARINA ABOAL[1] AND OLAF WERNER[2]



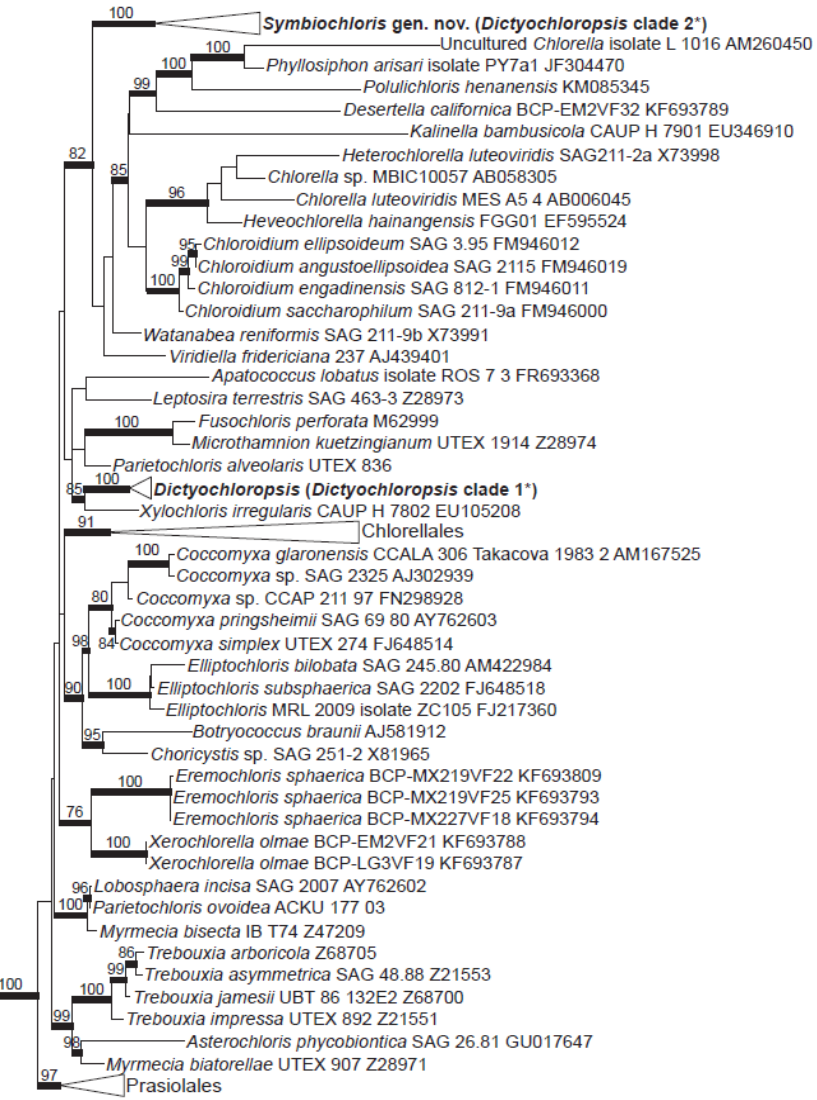


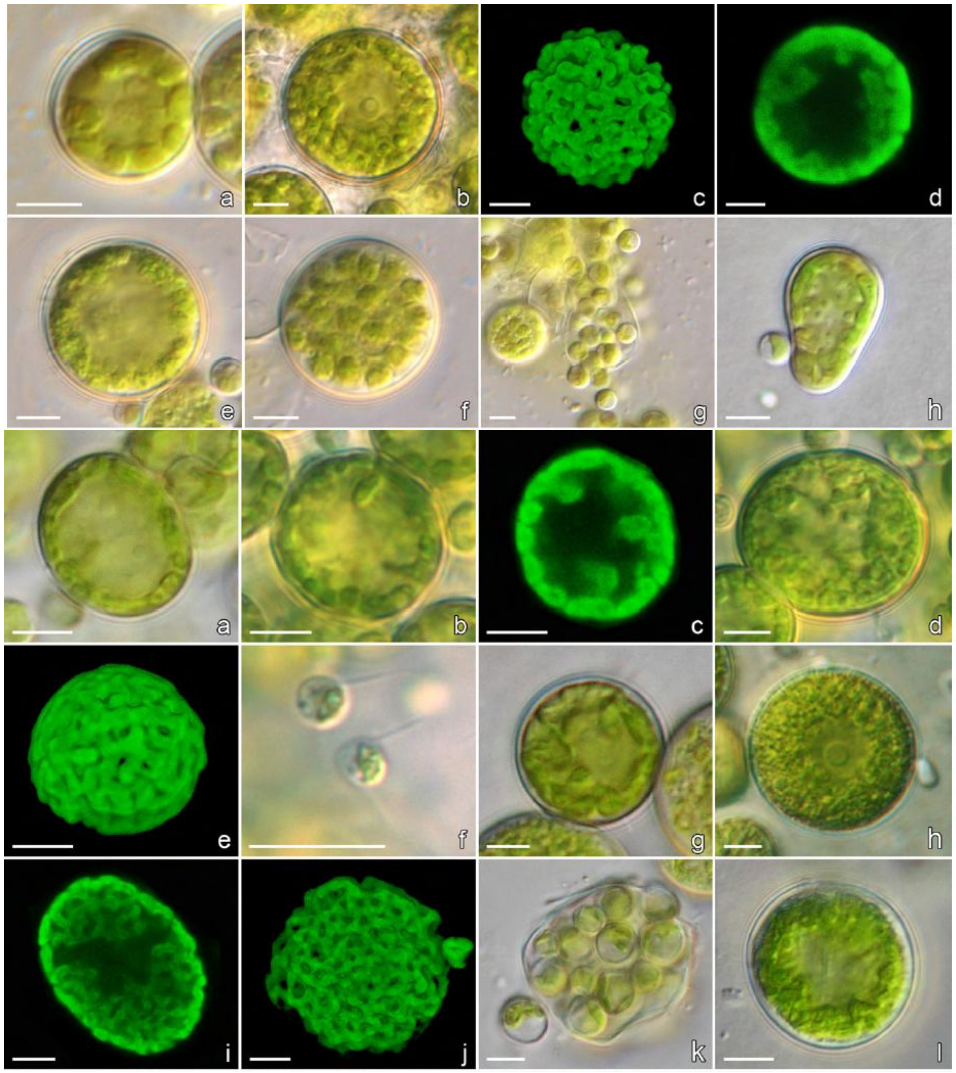




Watanabeales, *Symbiochloris*

- aerophytic alga, lichen symbiont





Škaloud et al. (2016): J Phycol 52, 599-617

Watanabeales

Zhu *et al. BMC Plant Biology* (2018) 18:365
https://doi.org/10.1186/s12870-018-1588-7

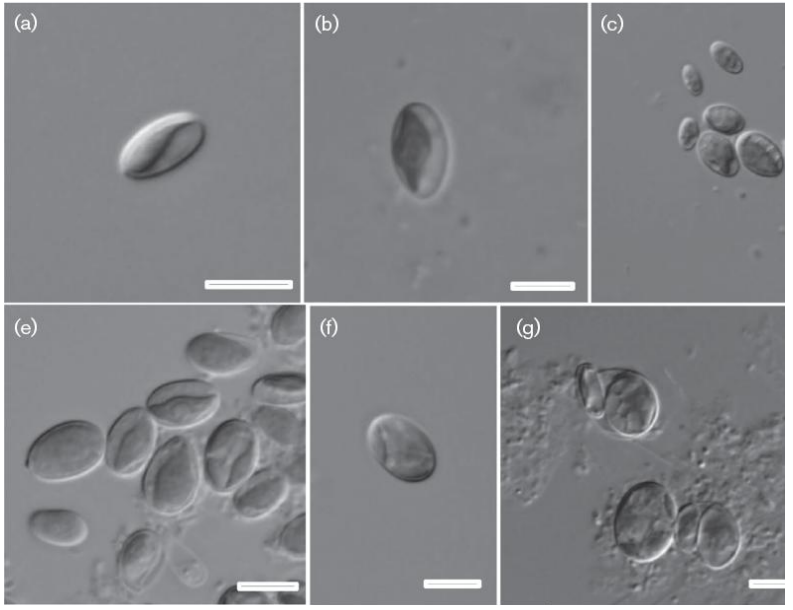
BMC Plant Biology

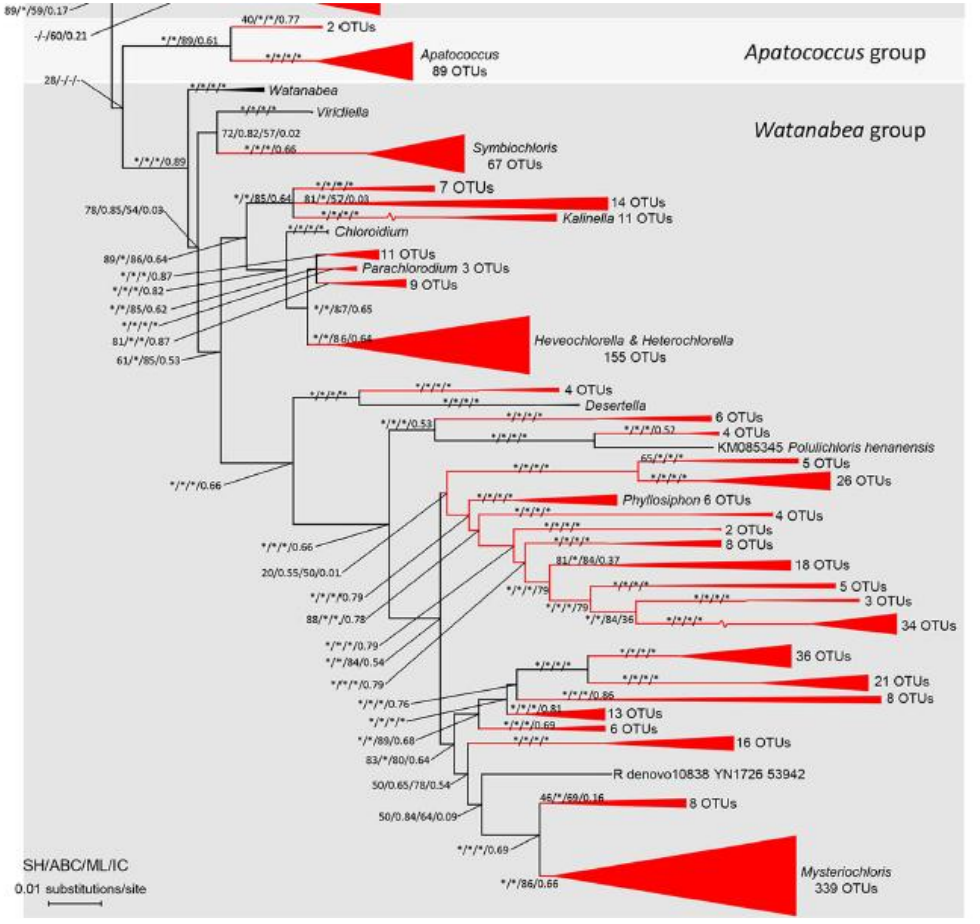
RESEARCH ARTICLE Open Access

Molecular characterization of eukaryotic algal communities in the tropical phyllosphere based on real-time sequencing of the 18S rDNA gene

Huan Zhu[1], Shuyin Li[1], Zhengyu Hu[2] and Guoxiang Liu[1*]

- a number of novel lineages
- *Mysteriochloris* as the most abundant lineage





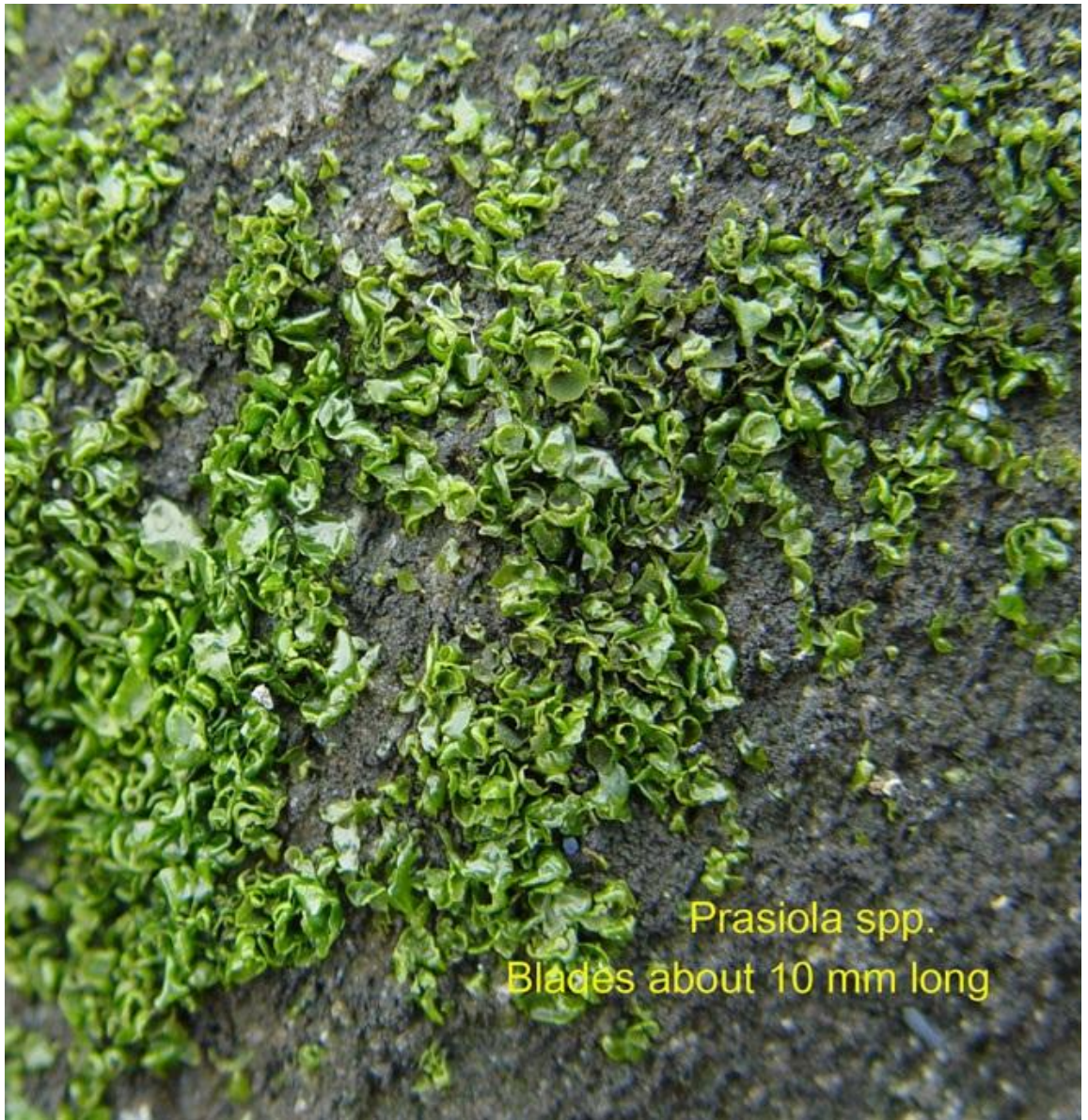
Apatococcus

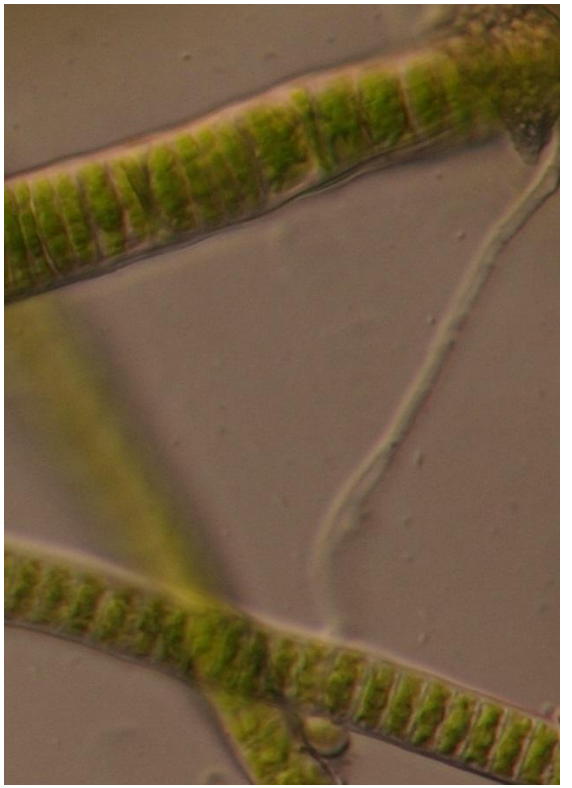
Apatococcus

- building facades, painted iron substrates

Microthamniales, *Microthamnion*

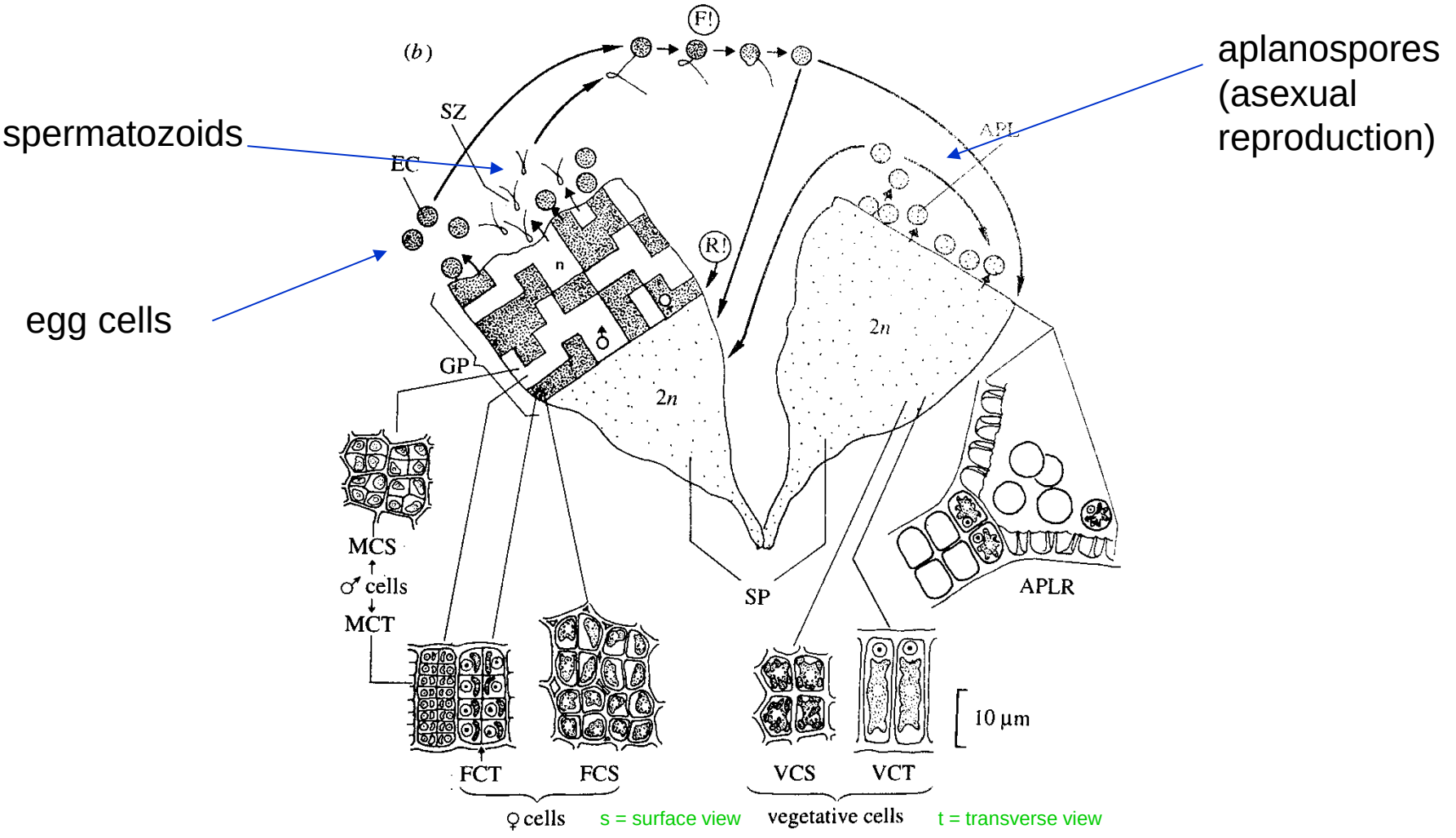
Prasiolales, *Prasiola*





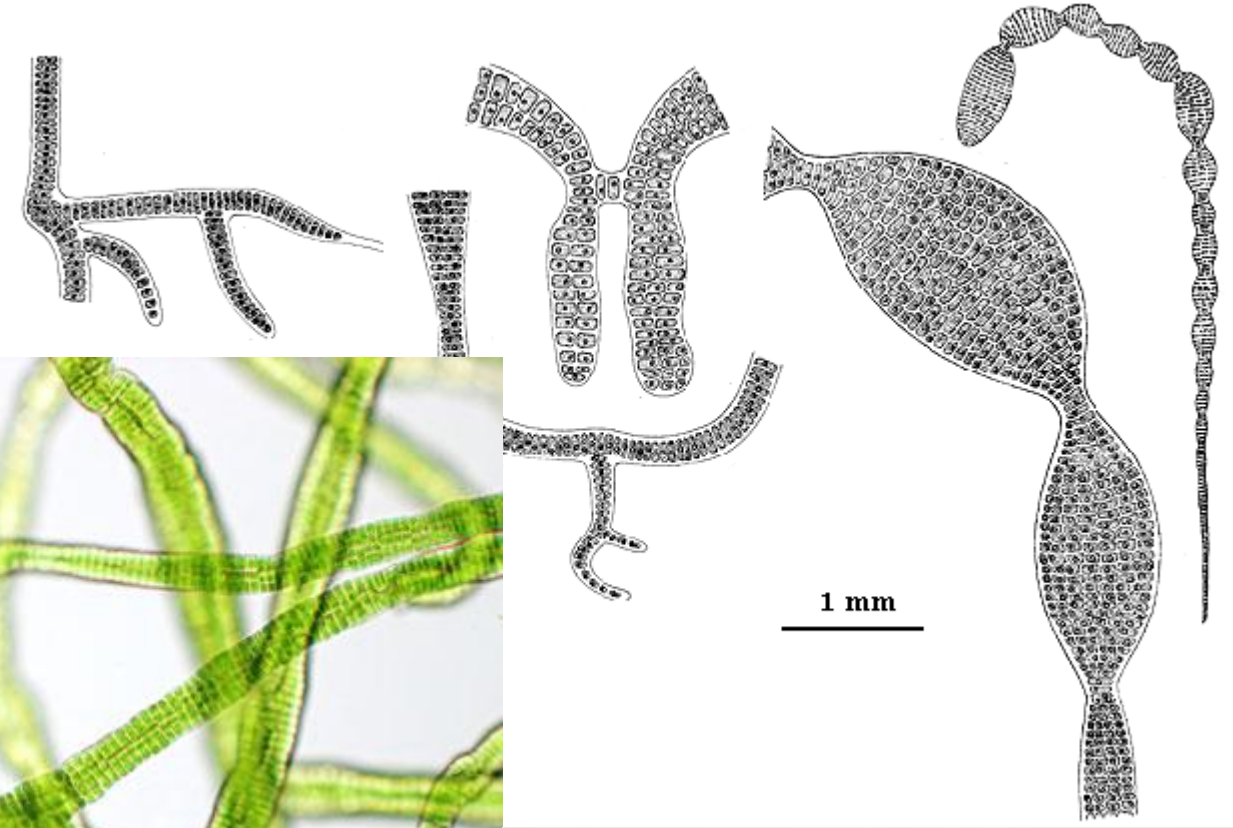
Prasiolales, *Prasiola*

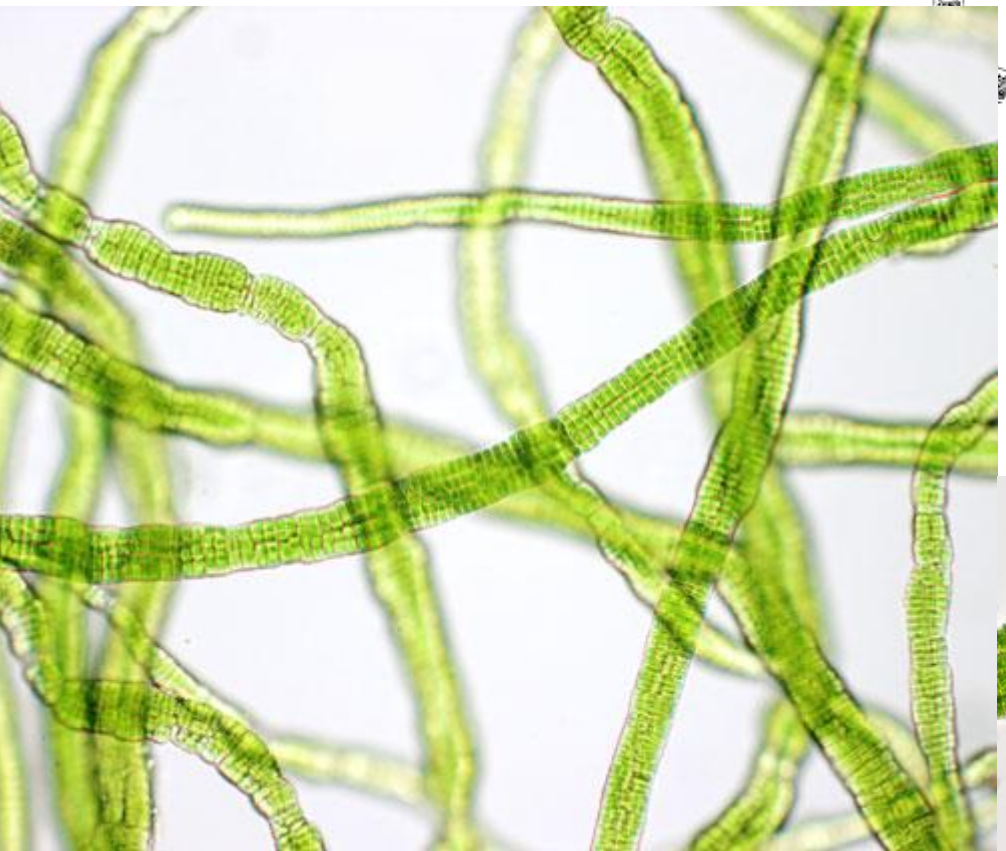
- mosaic sexual reproduction

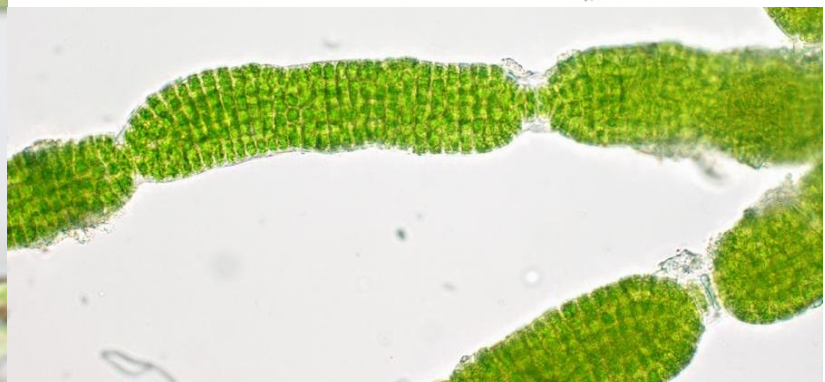


Prasiolales, *Rosenvingiella*

haploid thallus,
zygotic meiosis

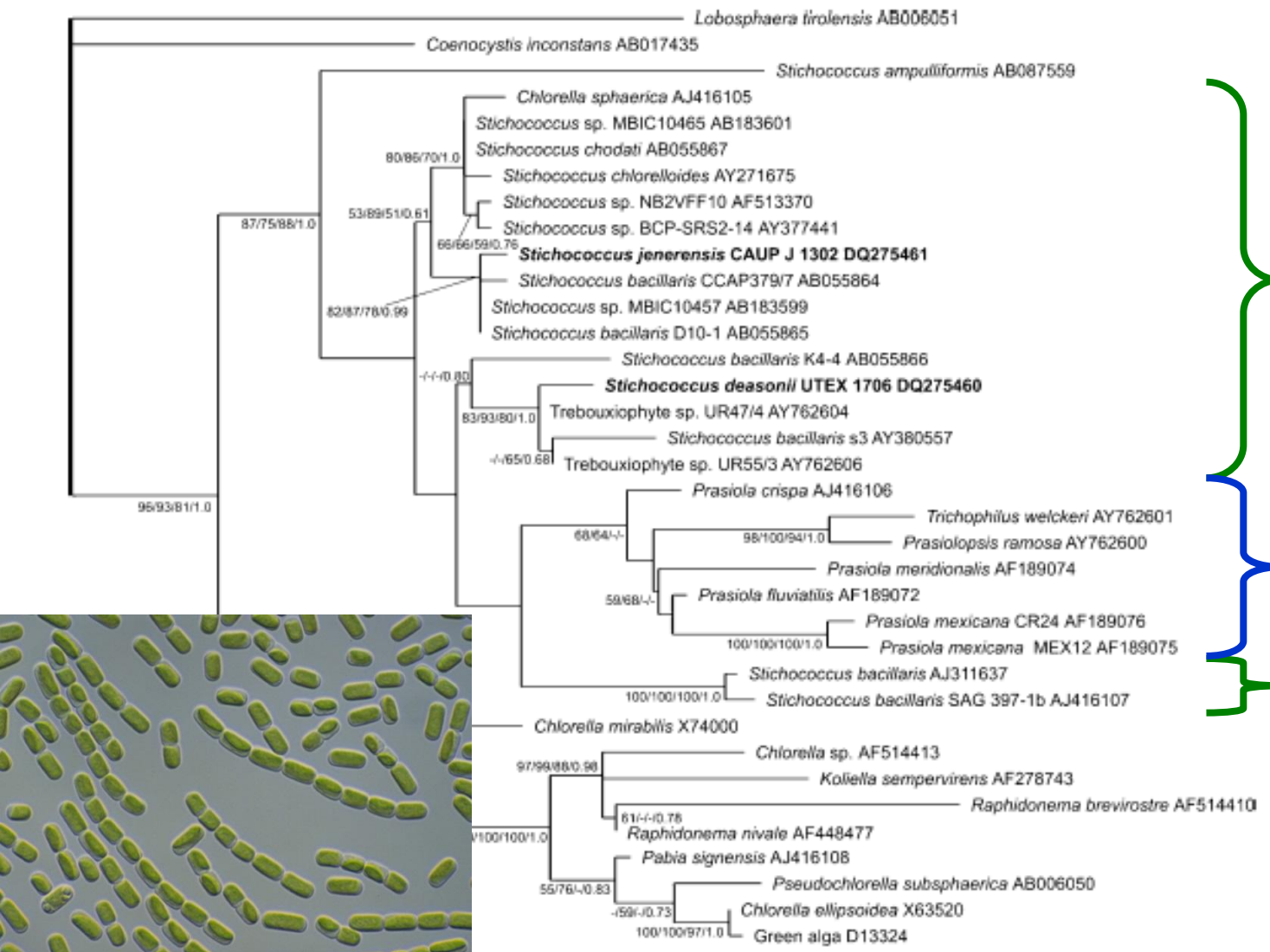




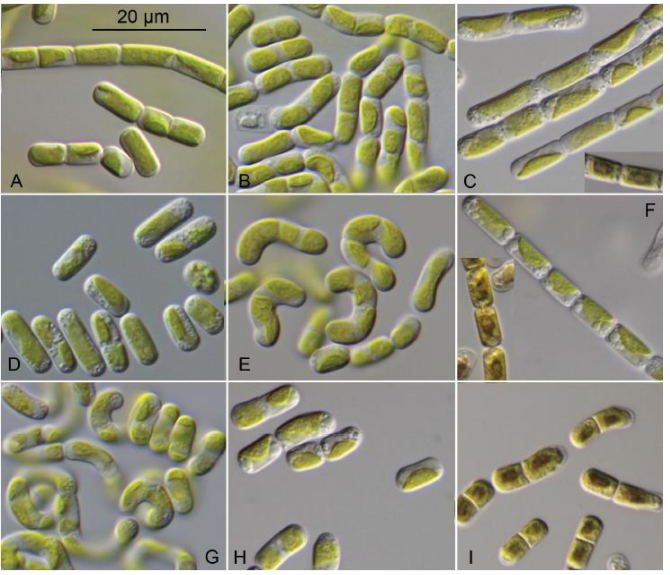


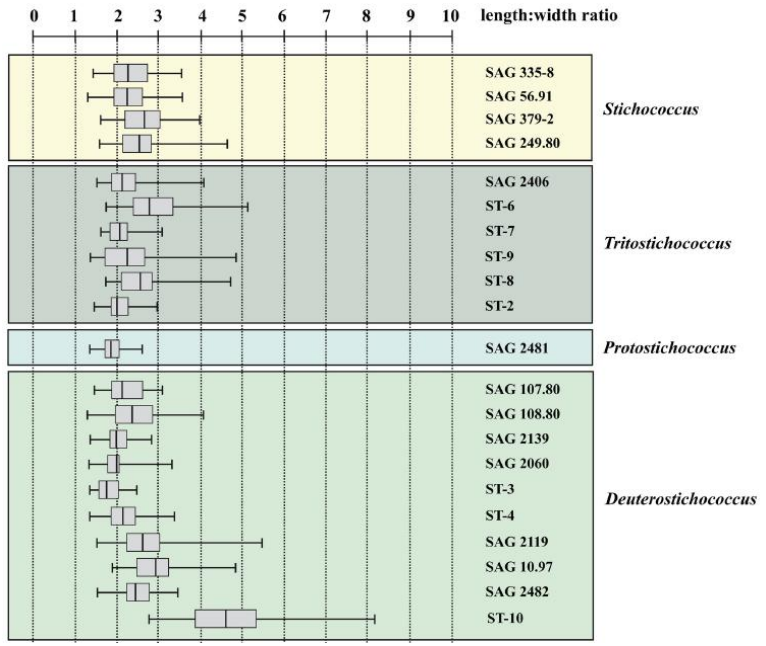
Prasiolales, *Stichococcus*

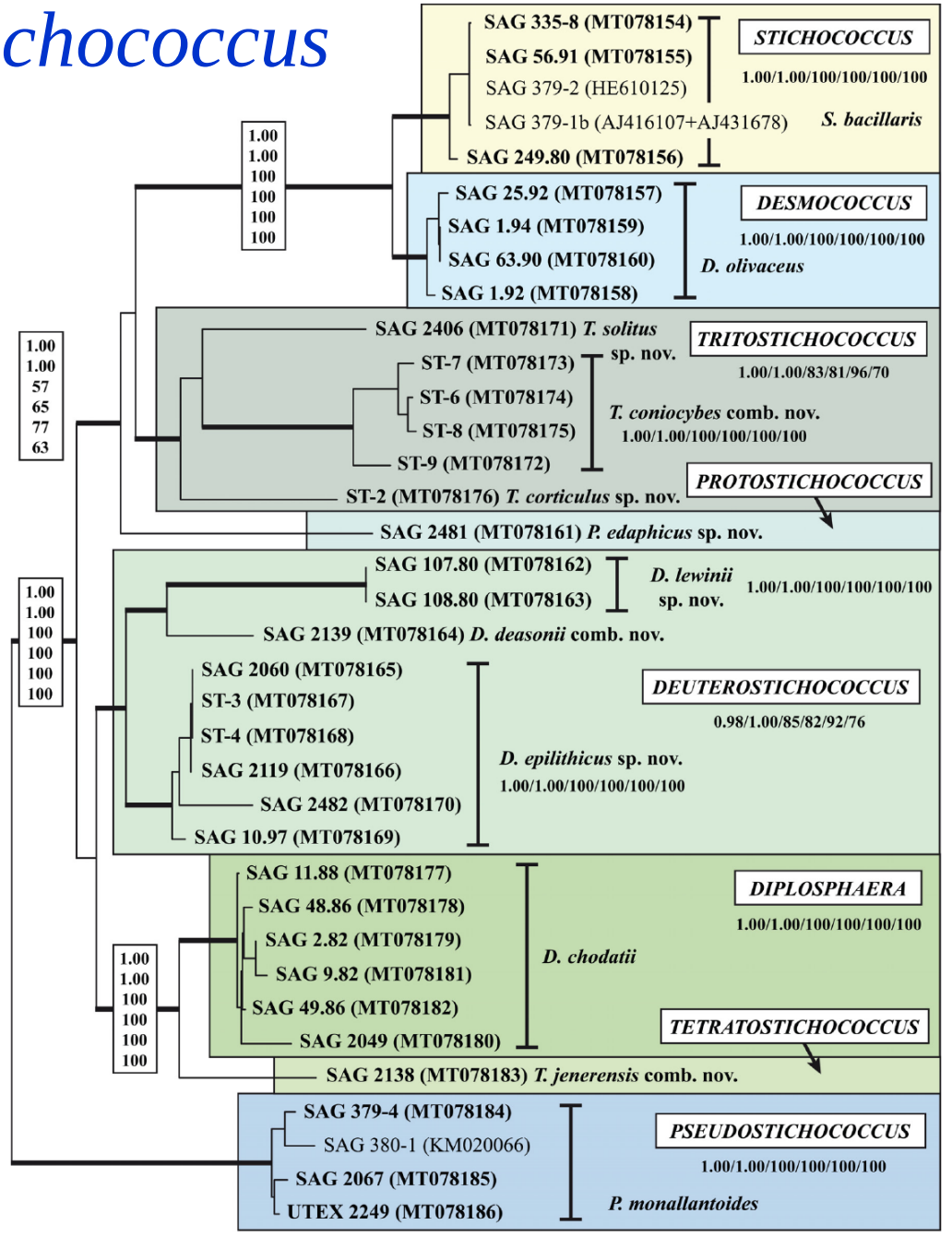
- *Prasiola* – crown group in *Stichococcus* lineage



Prasiolales, *Stichococcus*

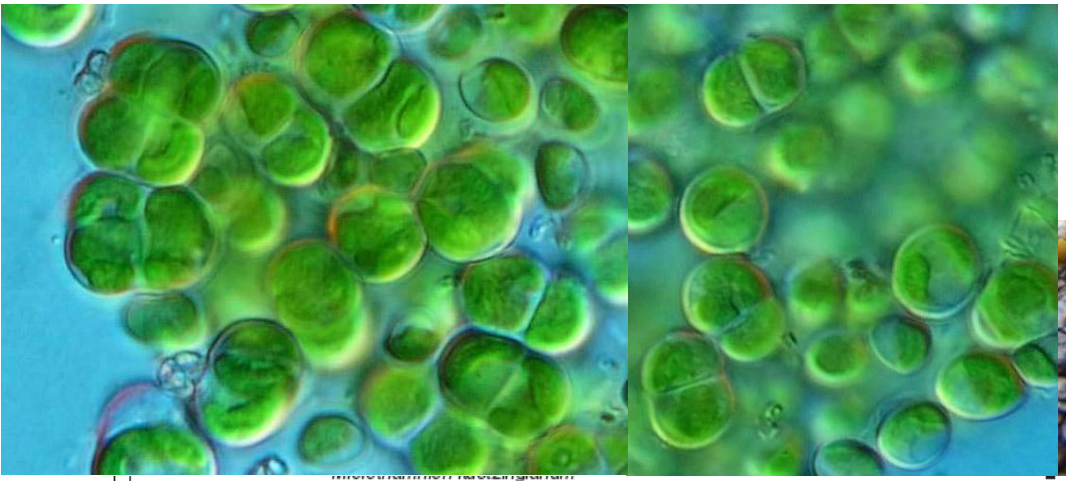






Prasiolales, *Diplosphaera*

- free living, lichen photobiont

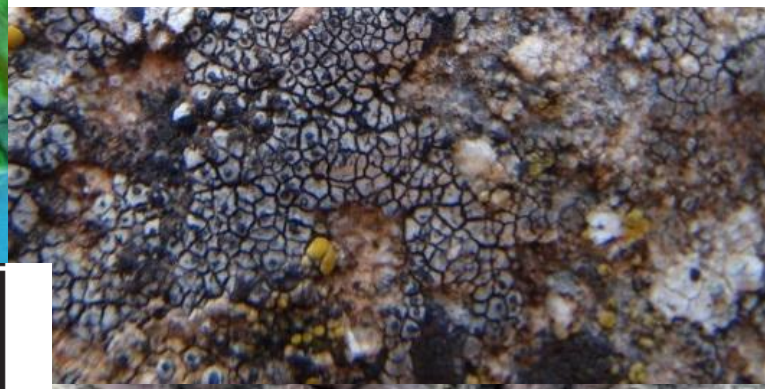


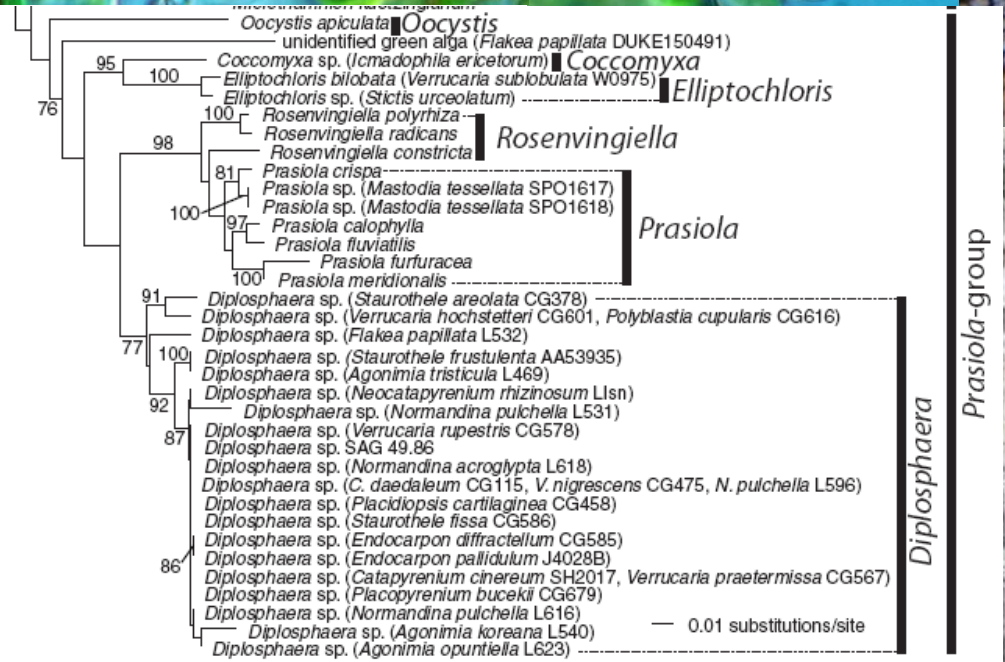
Eur. J. Phycol., (2011), **46(4)**: 399–415

Taylor & Francis

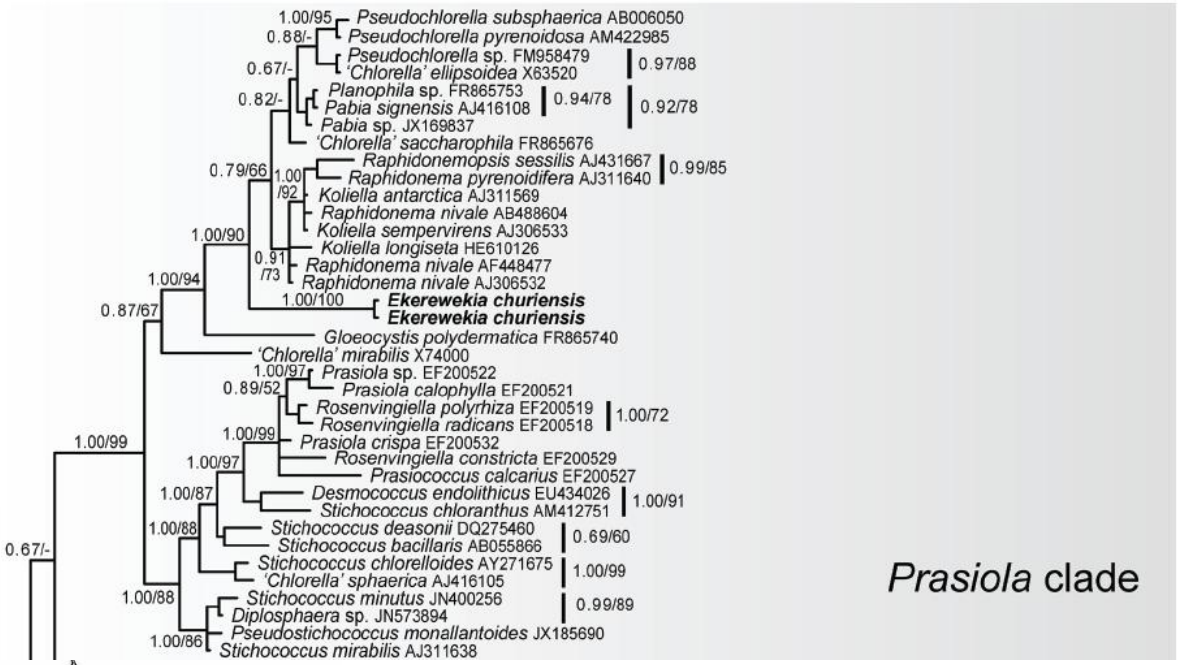
Revisiting photobiont diversity in the lichen family Verrucariaceae (Ascomycota)

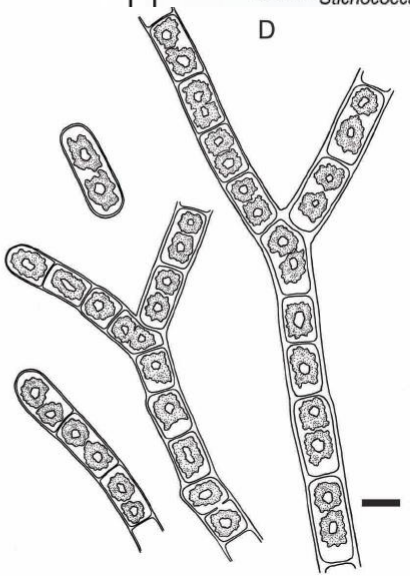
HOLGER THÜS[1], LUCIA MUGGIA[2], SERGIO PÉREZ-ORTEGA[3], SERGIO E. FAVERO-LONGO[4], SUZANNE JONESON[5], HEATH O'BRIEN[6], MATTHEW P. NELSEN[7,8], RHINAIXA DUQUE-THÜS[1], MARTIN GRUBE[2], THOMAS FRIEDL[9], JULIET BRODIE[1], CARRIE J. ANDREW[7,10], ROBERT LÜCKING[7], FRANÇOIS LUTZONI[11] AND CÉCILE GUEIDAN[1]





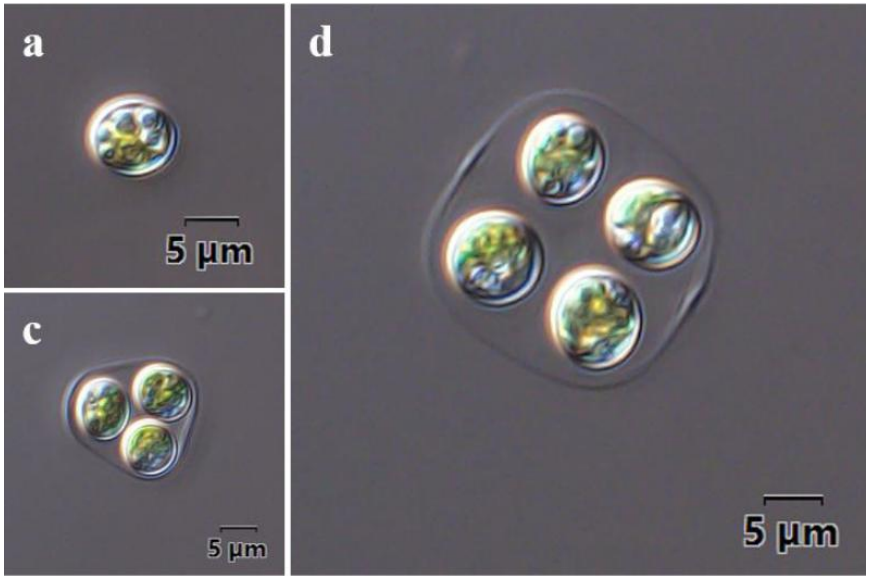
Prasiolales, *Ekerewekia*



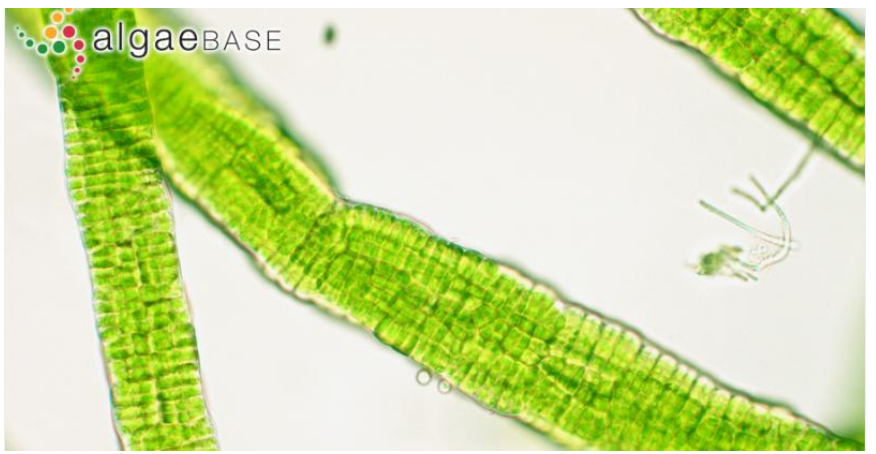


Kaštovský et al. 2016, Phytotaxa

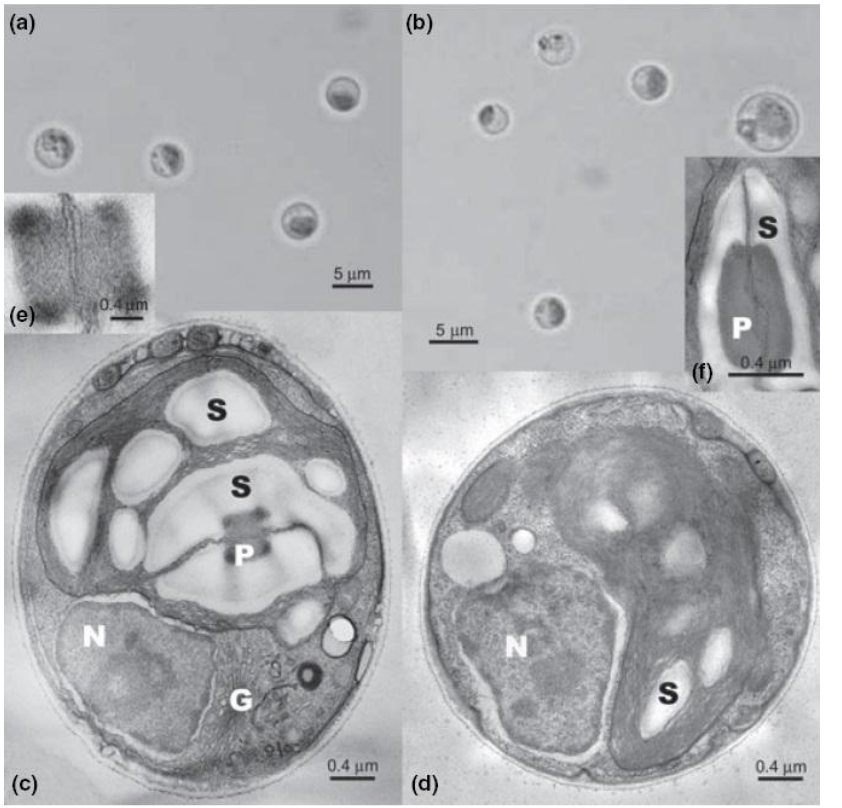
Marine Trebouxiophyceae



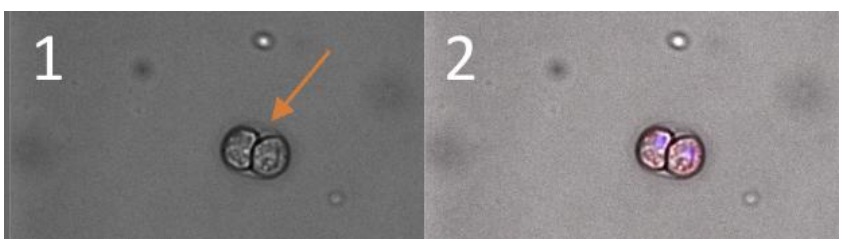
Euchlorocystis marina (2022)



Rosenvingiella

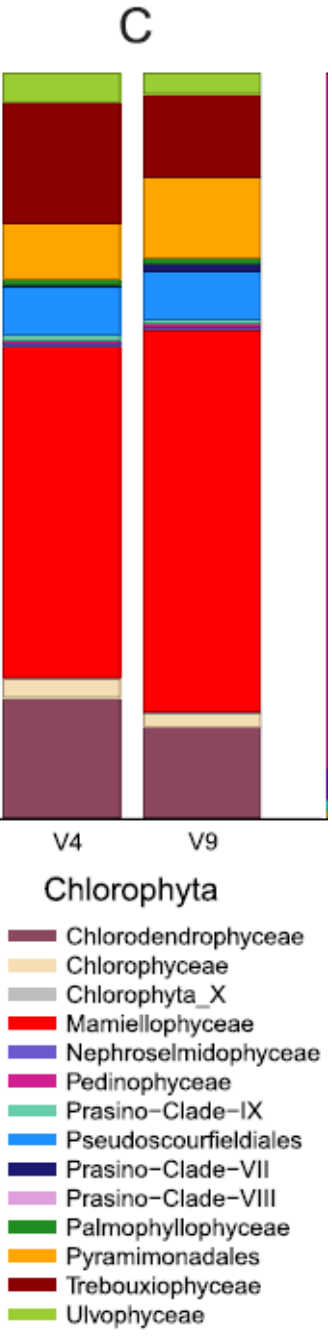


Marinichlorella kaistiae (2017)



Nannochloris desiccata (2022)

Marine Trebouxiophyceae

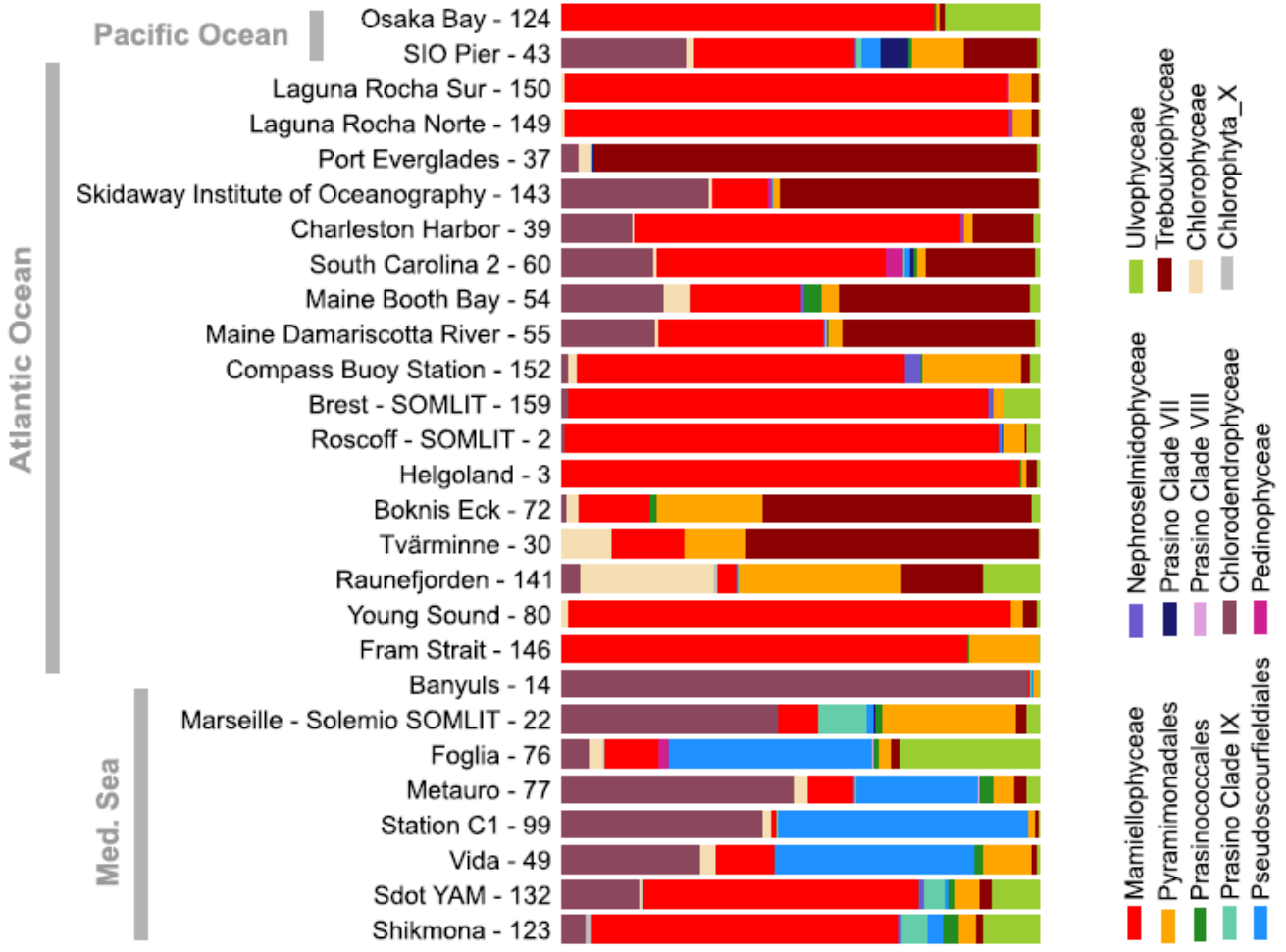


environmental microbiology

Environmental Microbiology (2018) **20**(2), 506–520 doi:10.1111/1462-2920.13952

Comparison of coastal phytoplankton composition estimated from the V4 and V9 regions of the 18S rRNA gene with a focus on photosynthetic groups and especially Chlorophyta

Margot Tragin,[1] Adriana Zingone[2] and Daniel Vaulot[1]*



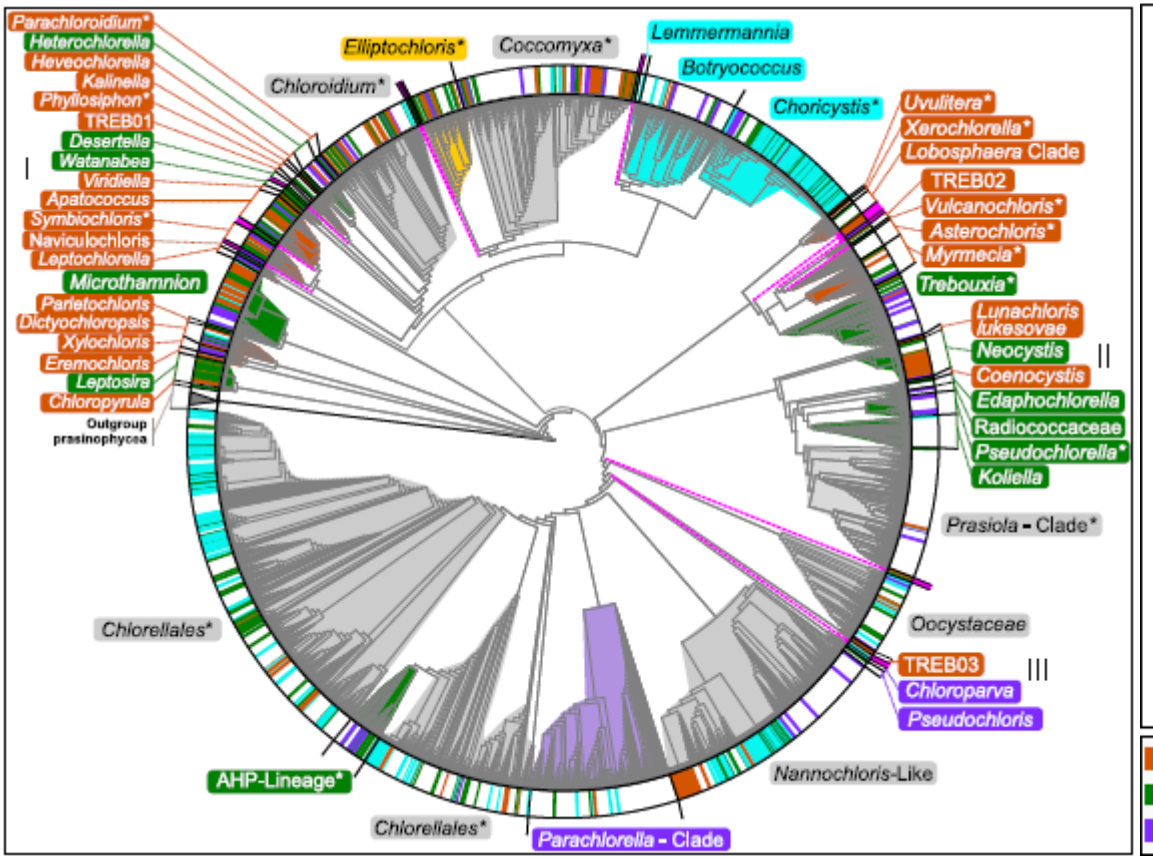
Marine Trebouxiophyceae

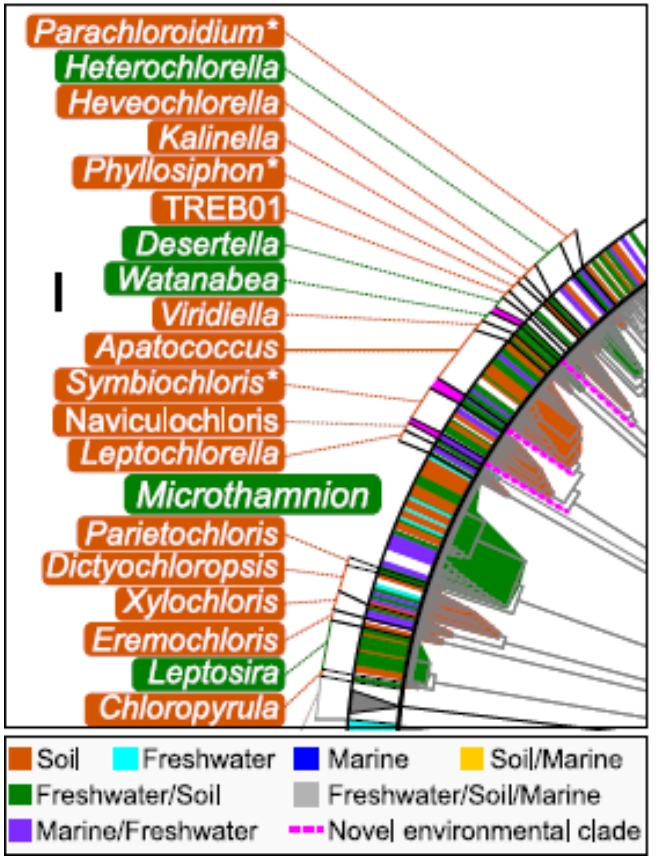
environmental microbiology

Environmental Microbiology (2019) **21**(10), 3885–3895 doi:10.1111/1462-2920.14738

Global distribution of Trebouxiophyceae diversity explored by high-throughput sequencing and phylogenetic approaches

Sebastian Metz,[1] David Singer,[2,3] Isabelle Domaizon,[4] Fernando Unrein[1] and Enrique Lara[5*]





Monophyly of Trebouxiophyceae

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ECOLOGY AND EVOLUTION

ORIGINAL RESEARCH ARTICLE
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New phylogenetic hypotheses for the core Chlorophyta based on chloroplast sequence data

Karolina Fučíková[1], Frederik Leliaert[2,3], Endymion D. Cooper[4], Pavel Škaloud[5], Sofie D'Hondt[2], Olivier De Clerck[2], Carlos F. D. Gurgel[6], Louise A. Lewis[1], Paul O. Lewis[1], Juan M. Lopez-Bautista[3], Charles F. Delwiche[4] and Heroen Verbruggen[7]*

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Phylogenetic relationships in the green algal phylum Chlorophyta have long been subject to debate, especially at higher taxonomic ranks (order, class). The relationships among three traditionally defined and well-studied classes, Chlorophyceae, Trebouxiophyceae, and Ulvophyceae are of particular interest, as these groups are species-rich and ecologically important worldwide. Different phylogenetic hypotheses have been proposed over the past two decades and the monophyly of the individual classes has been disputed on occasion. Our study seeks to test these hypotheses by combining high throughput sequencing data from the chloroplast genome with increased taxon sampling. Our results suggest that while many of the deep relationships are still problematic to resolve, the classes Trebouxiophyceae and Ulvophyceae are likely not monophyletic as currently defined. Our results also support relationships among several trebouxiophycean taxa that were previously unresolved. Finally, we propose that the common term for the grouping of the three classes, "UTC clade," be replaced with the term "core Chlorophyta" for the well-supported clade containing Chlorophyceae, taxa belonging to Ulvophyceae and Trebouxiophyceae, and the classes Chlorodendrophyceae and Pedinophyceae.

Keywords: chloroplast DNA, Chlorophyta, fast site removal, green algae, multi-gene phylogeny, molecular systematic, phylogenomics, Viridiplantae

Monophyly of Trebouxiophyceae

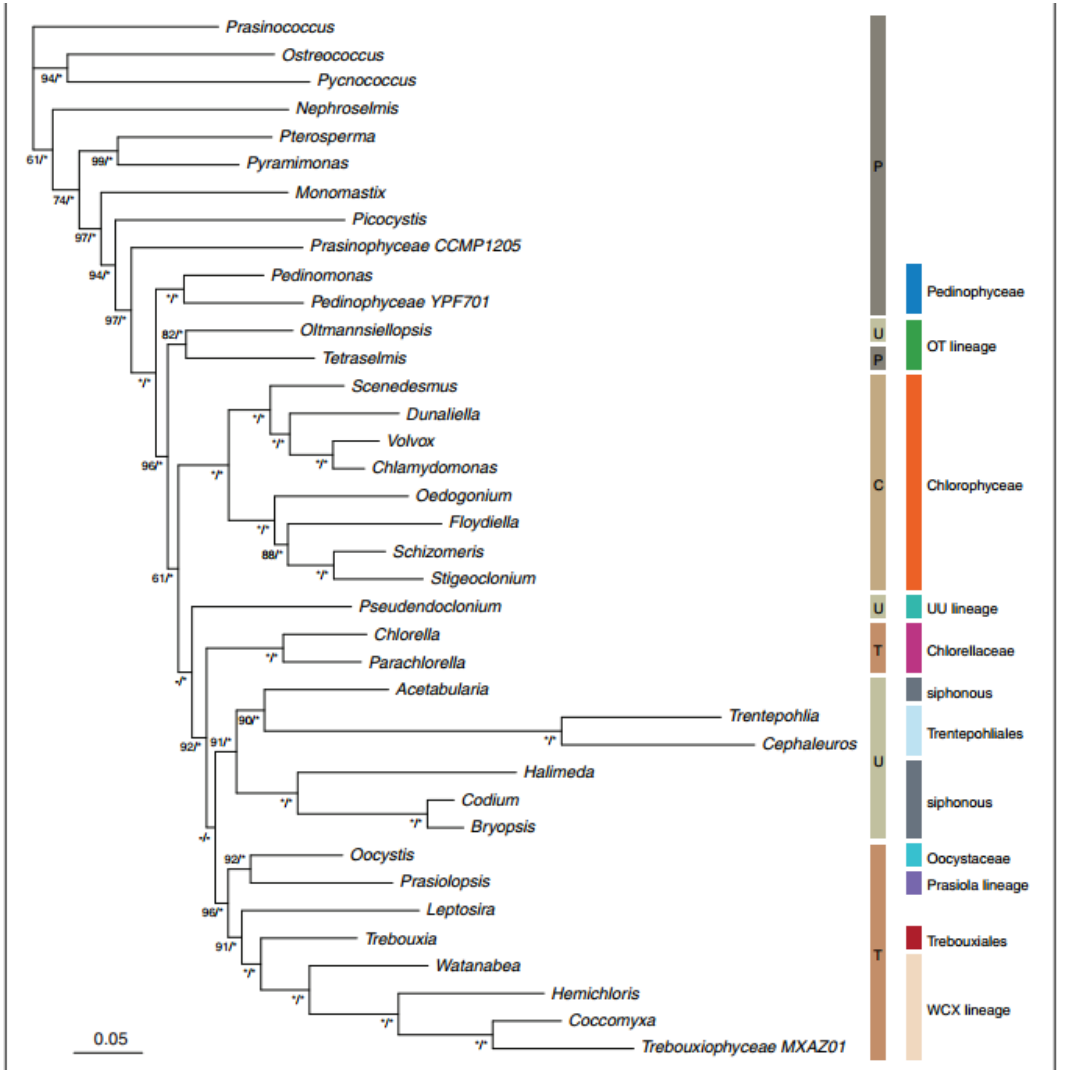

FIGURE 3 | Maximum likelihood phylogeny inferred from the genome-scale alignment (80% slowest sites). Bootstrap percentages and Bayesian posterior probabilities (MrBayes) are indicated along branches. The classical classication into Prasinophyceae (P), Chlorophyceae (C), Ulvophyceae (U) and Trebouxiophyceae (T) as well as the lineage-based classication discussed in the present paper are indicated to the right of the phylogeny. Values under 60 BS and 0.90 BPP are indicated as -, values of 100 BS and 1.00 BPP as *.

Neoproterozoic origin and multiple transitions to macroscopic growth in green seaweeds

Andrea Del Cortona[a,b,c,d,1], Christopher J. Jackson[e], François Bucchini[b,c], Michiel Van Bel[b,c], Sofie D'hondt[a], Pavel Škaloud[f], Charles F. Delwiche[g], Andrew H. Knoll[h], John A. Raven[i,j,k], Heroen Verbruggen[e], Klaas Vandepoele[b,c,d,1,2], Olivier De Clerck[a,1,2], and Frederik Leliaert[a,l,1,2]