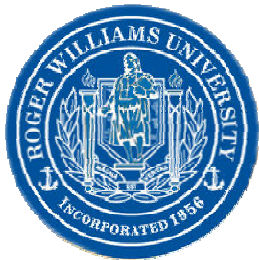




Introduction to the Classification of Green Algae



Brian Wysor, Ph.D.
Roger Williams University



Pan-American Advanced Studies Institute
Advanced Methods in Tropical Phycology

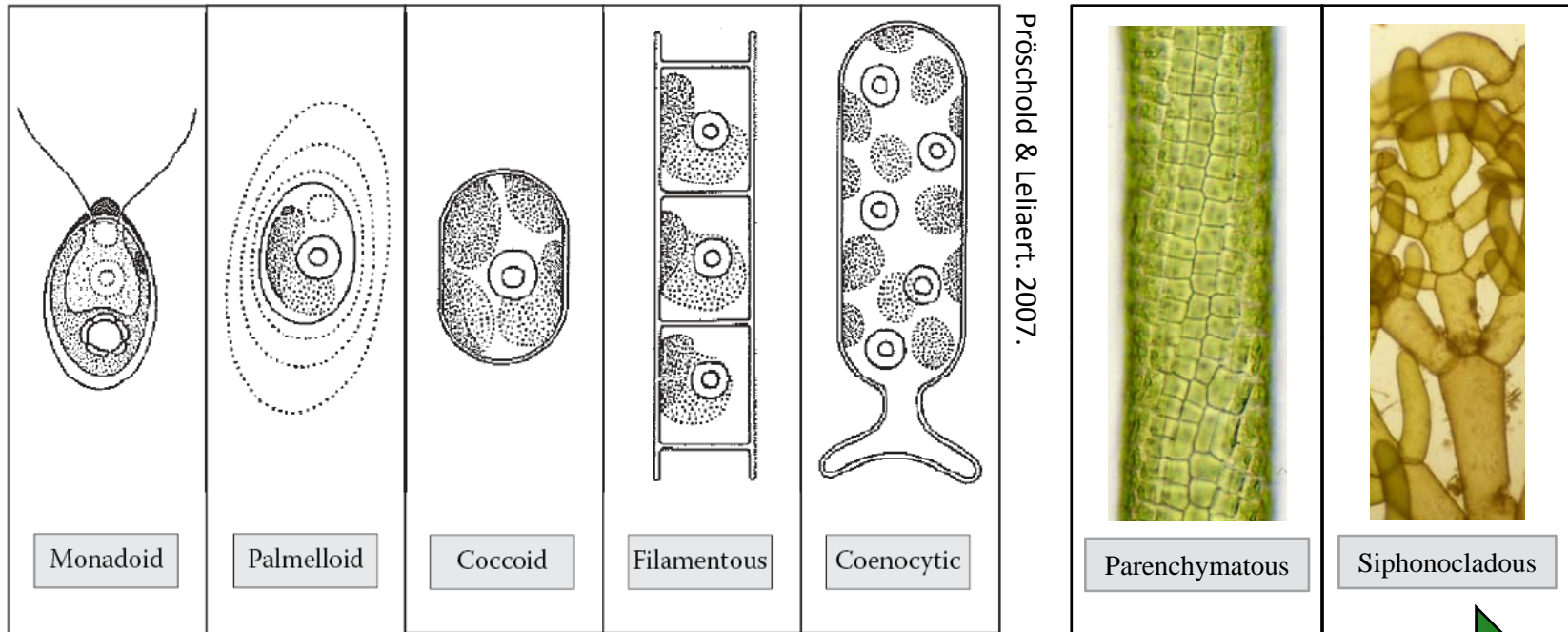


Classification

- 20+ classes of green algae have been described since Linnaeus
- Many criteria have been used to establish classes
 - Morphology
 - Ultrastructure
 - + mitosis, cell division, cytokinesis, flagellar apparatus
 - Life history patterns
 - Molecular
 - Primarily rRNA genes, *rbcL*
- Ambiguity remains, but consensus is emerging



Classification: Morphological Concept



Pröschold & Leilaert, 2007.

Photos by Huang Su-fang.

Evolution of structural complexity

- Premise
 - Primitive unicells evolved structural complexity over time
 - Morphological divergence distinguishes groups



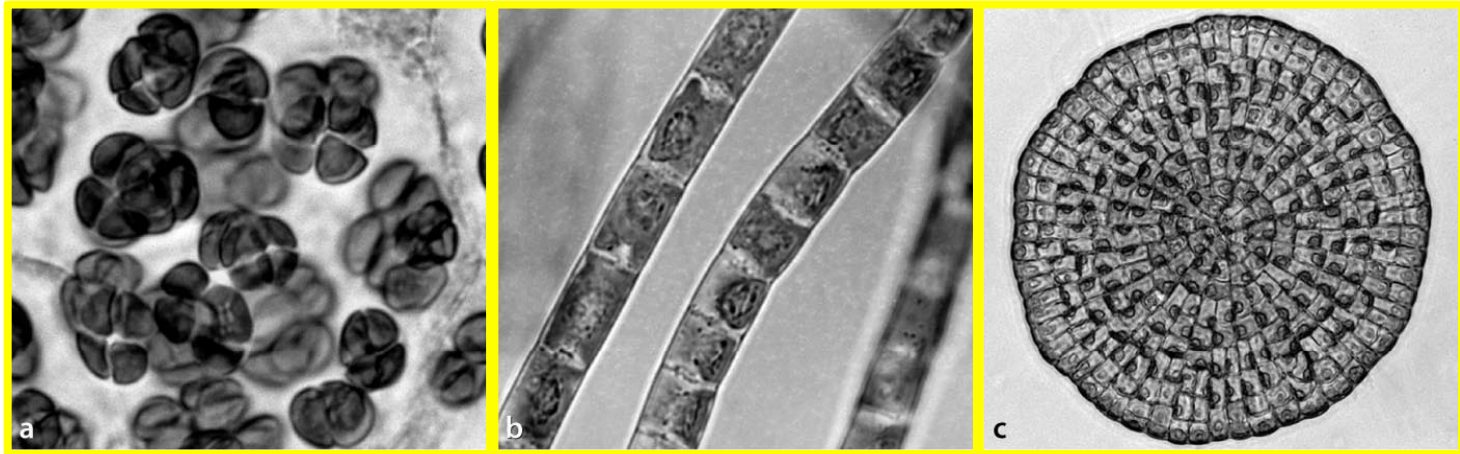
Pan-American Advanced Studies Institute
Advanced Methods in Tropical Phycology



Problems with Morphological Concept

- Selective environmental pressure may drive convergence
 - Biologically/genetically distinct species appear similar

Charophyceae



Chlorophyceae
Ulvophyceae

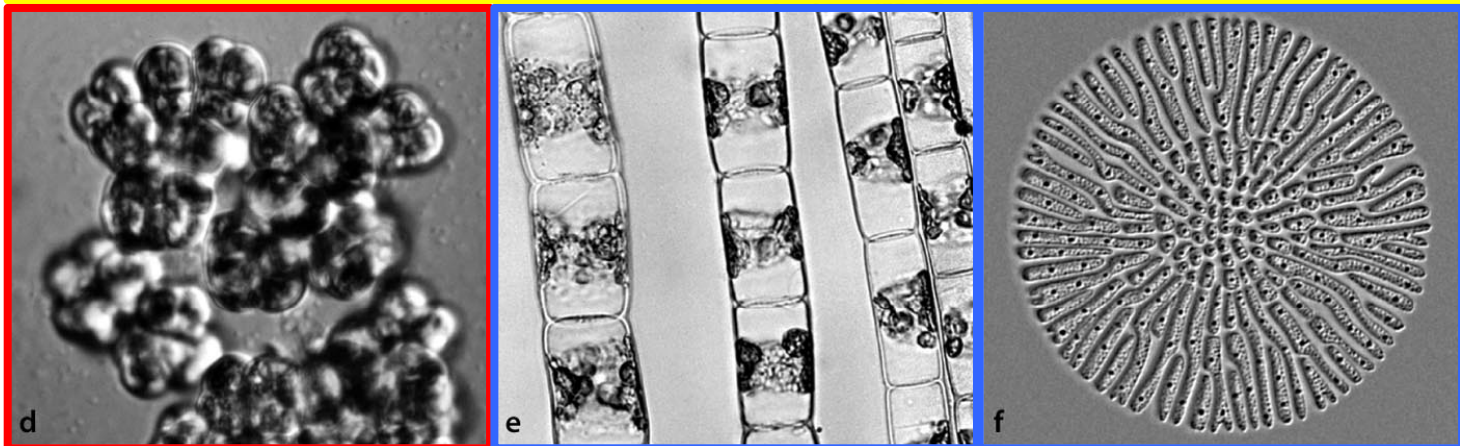


Fig. 16.18 Graham et al. 2008.

© 2009 Pearson Education, Inc.

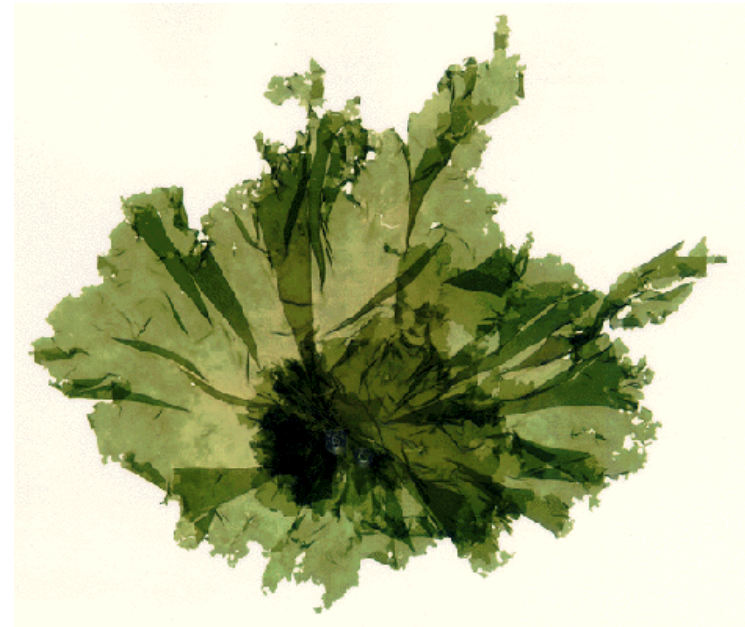
Morphological Convergence w/in Class



Class: Ulvophyceae

Order: Ulvales

Genus: *Ulvaria*



Ulvophyceae

Ulotrichales

Monostroma



Pan-American Advanced Studies Institute
Advanced Methods in Tropical Phycology



Chlorophyta: Morphological Convergence

- How can green algae be classified if they exhibit both divergent and convergent patterns of morphology?

7 Systematics of the green algae: conflict of classic and modern approaches

Thomas Pröscholdt and Frederik Lelièvre

CONTENTS

| | |
|--|-----|
| Introduction | 124 |
| How are green algae classified? | 125 |
| The morphological concept | 125 |
| The ultrastructural concept | 125 |
| The molecular concept (phylogenetic concept) | 131 |
| Classic versus modern approaches, problems with identification of species and genera | 134 |
| Taxonomic revision of genera and species using polyphasic approaches | 139 |
| Polyphasic approaches used to characterize the genera <i>Ongania blattaria</i> and <i>Leobolium</i> | 140 |
| Defining phylogenetic species by a multi-gene approach in <i>Mizozonopsis</i> and <i>Polytrichia</i> | 143 |
| Conclusions | 144 |
| Biodiversity of green algae based on taxonomic revision using polyphasic approaches | 144 |
| Reconstructing the green algal tree by multi-gene and whole-genomic analysis | 146 |
| Outlook | 147 |
| How should we approach taxonomic revision using polyphasic approaches? | 147 |
| Acknowledgments | 148 |
| References | 148 |

ABSTRACT

Traditionally the green algae were classified in orders or classes according to the morphological species concept, for example, monotypic species (flagellates) were summarized in the order Volvocales, coecoids in the Chlorococcales, filaments in the Ulvales or Chlorophytales, and siphonocladous algae in the Chlorophytales or Siphonocladales. Later, a new classification was proposed based on ultrastructural investigations of the basal bodies in the flagellar apparatus and cell division. The species with basal bodies at clockwise (CW) or directly opposite (DO) orientation were classified in the class Chlorophyceae, the counter-clockwise (CCW) orientated species in the Ulvophyceae and Trebouxiophyceae (= Pleurostomophyceae). Phylogenetic analyses of nuclear-ribosomal SSU and ITS rDNA sequences have basically confirmed the classification based on ultrastructural characters. However, most genera and orders are polyphyletic and the relationships between



Ultrastructural Concept

- Mattox & Stewart (1984) proposed new Class-level taxonomy on the basis of basal body orientation
 - 1st radiation of green algae occurred among unicellular flagellates
 - Numerous ancient flagellate lineages diversified into contemporary forms along different evolutionary paths, but many with similar morphological results
- 4 different basal body patterns identified



Basal Body Orientations

Ancestral condition

Chlorophyceae (p)

Ulvophyceae, Trebouxiophyceae (p)

Chlorophyceae (b)

Charophyceae, Drier Green Algae (e)

CHOROPHYTA

STREPTOPHYTA

Molecular Concept

- Elucidation of green algal phylogeny in molecular context commenced in early 1990s
- Early studies
 - confirmed distinction between Chlorophyta & Streptophyta already suggested by cellular and ultrastructural characters elucidated from EM
 - recognized 5 lineages:
 - Prasinophyceae, Chlorophyceae, Trebouxiophyceae, Ulvophyceae, Streptophyta + Land plants
 - Subsequent studies have confirmed these lineages, but relationships among & within the lineages remains unclear



Molecular Concept

(McCourt & Lewis 2004, Working Classification)

molecular data support the recognition of two phyla and a poorly resolve graded of early diverging flagellates informally known as Prasinophyceans

Chlorophyta

Streptophyta

(Charophyceae +
Drier Green Algae)

Viridiplantae or Chlorobionta

10

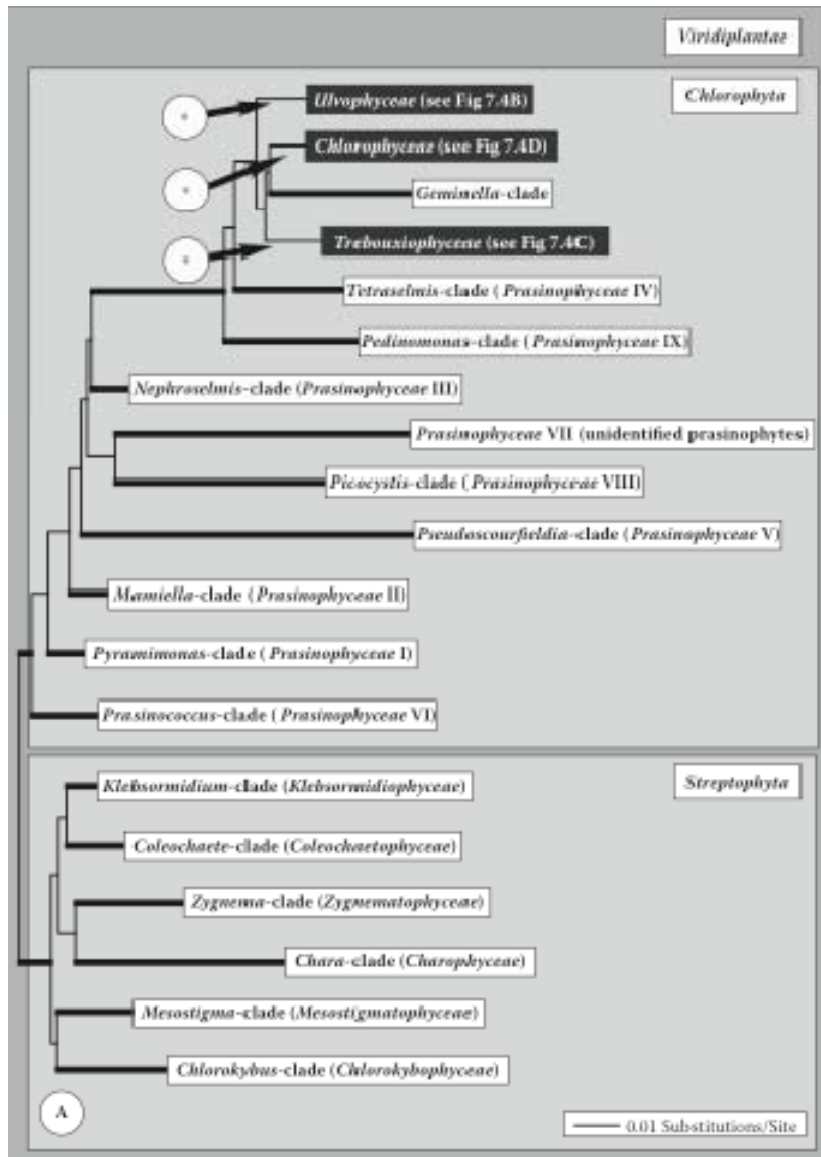


Pan-American Advanced Studies Institute
Advanced Methods in Tropical Phycology



SSU rDNA Molecular Concept

(Pröschold & Leliaert 2007)



- Chlorophyta + Streptophyta recovered
- UTC clade recovered with low BS support (no bold lines)
- Poorly resolved Prasinophycean grade

FIGURE 7.4 Molecular phylogeny of the Viridiplantae based on SSU rDNA sequence comparisons. The phylogenetic tree shown was inferred by the neighbor-joining method based on distances of 1668 aligned positions of 428 taxa using PAUP 4.0b10 (Sudolma, 2002). Support values of the clades (A) through (D) were calculated using the bootstrapped (BS) 1000 iterations and 50% substitution by Madhonia et al. (2004) and Buckley (2002), De Siqueira and Chandra (2002). Bootstrap percentage values $\geq 70\%$ are marked by bold brackets given for major support (using 1000000 bootstrapped 1000 replicates). The non-phylogenetic clades are given in italic names along a representative taxon. (A) Phylogenetic tree of the Chlorophyta and Streptophyta (7 taxa). For the classes Chlorophyceae and Trebouxiophyceae are represented by few taxa in this analysis (bold mark). (B) Streptophyta (10 taxa). The clades containing species of the three charophytes (non-italic) marked by an asterisk were not included in bootstrap analyses, however they were separately analyzed in part of the tree (B and marked). (C) Black

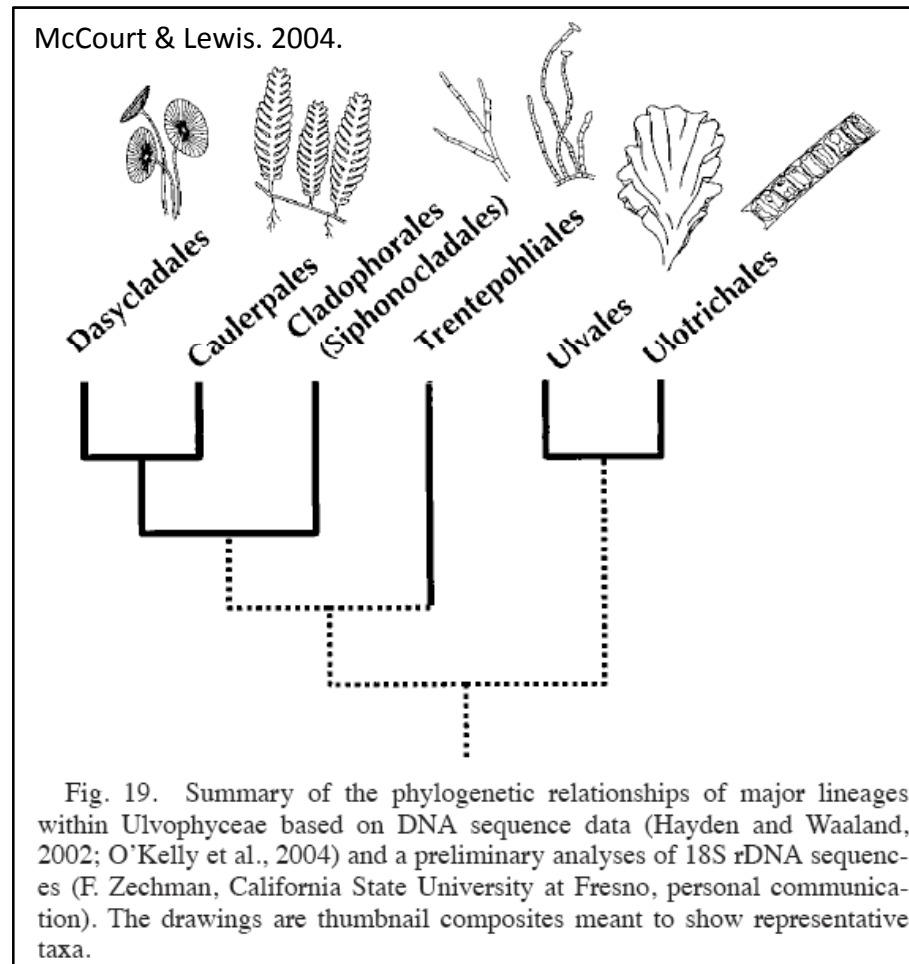
Class Ulvophyceae

- Most macroscopic marine green algae belong to Class Ulvophyceae
- Ulvophyceae is circumscribed on the basis of a suite of pleisiomorphic characters
 - Closed mitosis, persistent spindle, furrowing, CCW, flagellate cells with scales
- The absence of well-defined, shared-derived characters has resulted in uncertain relations within the class



Class Ulvophyceae

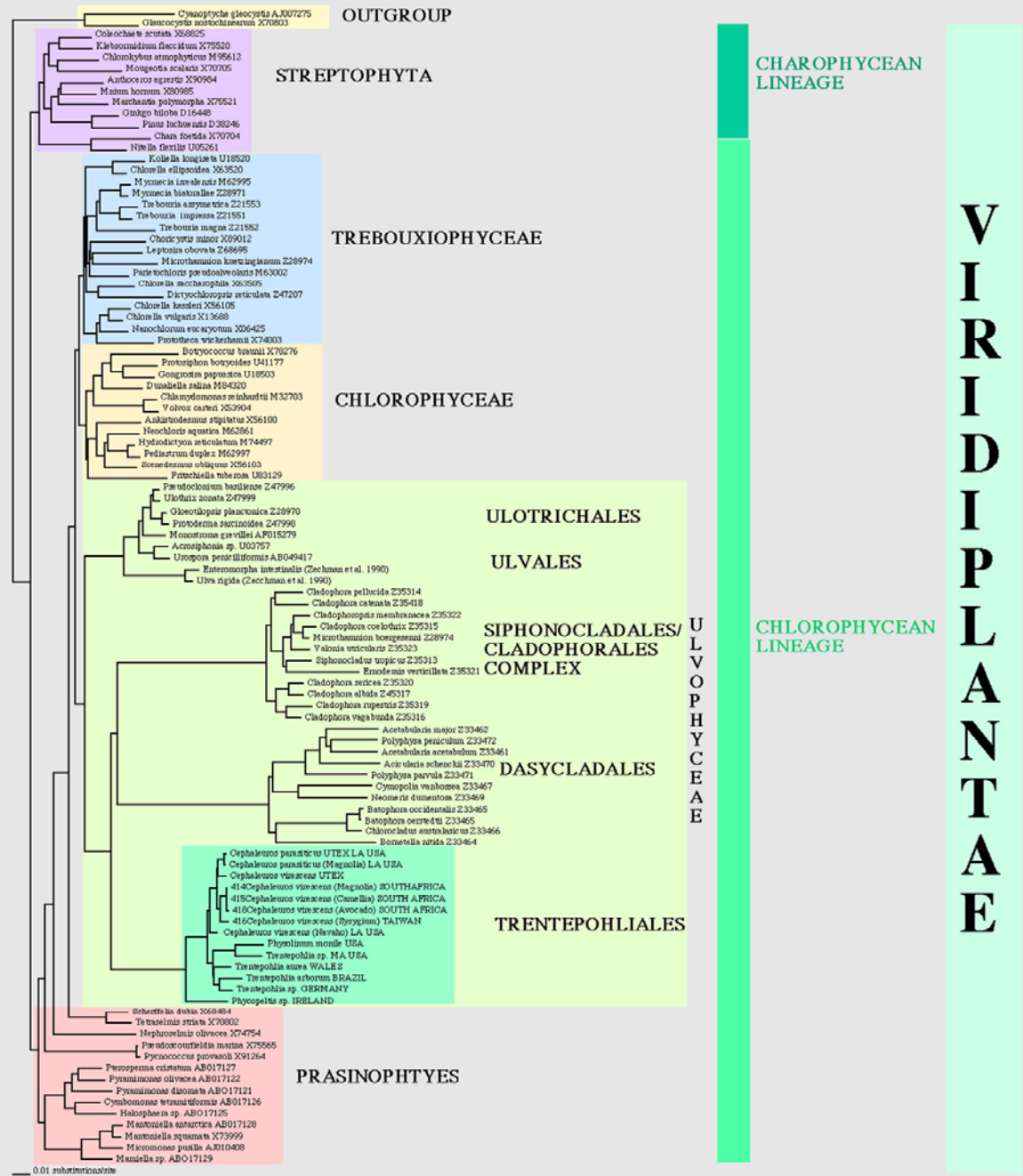
- Generally, 5 (or 6) orders are distinguished
 - flagellar apparatus
 - zoosporangial & gametangial structures
 - life history
- Orders are generally supported by molecular analysis, but relationships among orders are largely uncertain



Molecular Concept

(Lopez-Bautista et al. 2002)

Figure 22. Maximum likelihood tree, estimated from Kimura two-parameter model of sequence evolution using Modeltest parameters. $-lnL = 22774.1914$. A total of 102 taxa with 1720 positions are represented in the phylogram. Genbank accession numbers are given after the scientific name.

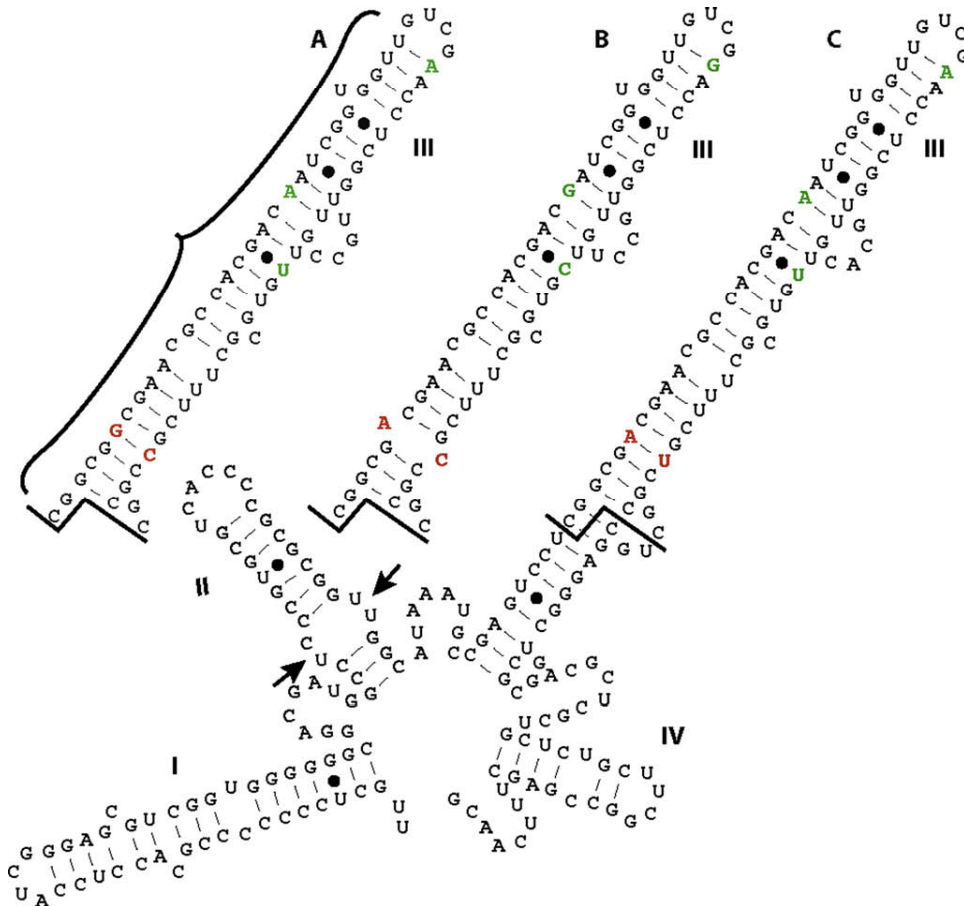


Sub-ordinal classification

- Generic and species level classification is frequently based on morphology which can be problematic
 - Phenotypic plasticity
 - Morphological convergence
- Integrated approaches are required to resolve these problems
- DNA sequencing (and distance clustering) is a start that can lead to the recognition of novel morphological, physiological or biological features



Z-clades & Biological Species inferred from ITS2 2° structure (see Coleman 2009)



- As ITS2 differences between potential mates increase, sexual compatibility and zygote productivity decrease
- Organisms that differ by even one CBC in helix III are completely unable to cross
- Identity for the entire ITS2 correlates with significant interbreeding potential.



Literature Cited

- Coleman, A. 2009. Is there a molecular key to the level of “biological species” in eukaryotes? A DNA guide. *Mol. Phylogen. Evol.* 50:197-203.
- Graham, L.E., Graham, J.M., & Wilcox, L.W. 2008. *Algae*, 2nd Ed., Benjamin Cummings, San Francisco, 616 p.
- Mattox, K.R. & Stewart, K.D. 1984. Classification of the green algae: a concept based on comparative cytology. Pp. 29-72, *In* Irvine, D.E.G. & John, D.M. (eds.), *The systematics of Green Algae*. The Systematics Association, Special Vol. 27, Academic Press, London.
- McCourt, R. & Lewis, L. 2004. Green algae and the origin of land plants. *Am. J. Bot.* 91: 1535-1556.
- Pröschold, T. & Leliaert, F. 2007. Systematics of the green algae: conflict of classic and modern approaches. Pp. 123-153 *In* Brodie, J. & Lewis, J. *Unravelling the algae: the past, present and future of algal systematics*. CRC press, Boca Raton, 376 p.
- van den Hoek, C., Mann, D.G., & Jahns, H.M. (1995) *Algae. An Introduction to Phycology*. Cambridge University Press, Cambridge.



*This presentation is a contribution of the
Pan-American Advanced Studies Institute*



***Advanced Methods in
Tropical Phycology***



14 Aug - 4 Sep 2009, Bocas Research Station,
Bocas del Toro, Panama

