1 Introduction to the Algae

- 1.1 Defining the Algae
- 1.2 Algal Body Types Microalgae Macroalgae
- 1.3 Algal Reproductive Types Asexual Reproduction Sexual Reproduction
- 1.4 A Survey of Algal Diversity
- 1.5 An Overview of Algal Photosynthesis
 The General Processes of Photosynthesis
 The Light-Acquisition Challenge
 The Photoprotection Challenge
 The Carbon-Fixation Challenge
- 1.6 Societal Issues Involving Algae

2 The Roles of Algae in Biogeochemistry

- 2.1 Cyanobacteria and the Origin of an Oxygen-Rich Atmosphere
- 2.2 Algae and the Carbon Cycle Algae and Organic Carbon Sequestration The Role of Algae in Carbonate Formation Impact of Modern Carbon Dioxide Levels on Algal Photosynthesis Carbon Concentration Mechanisms of Cyanobacteria Carbon Concentration Mechanisms of Eukaryotic Algae Algal Use of Organic Carbon
- 2.3 Mineral Limitation of Algal Growth
- 2.4 Algae and the Nitrogen Cycle
- 2.5 Iron Limitation of Algal Growth in the Oceans
- 2.6 Algae and the Sulfur Cycle
- **2.7 Algal Production of Halocarbon Compounds** Text Box 2.1 Remote Sensing of Phytoplankton

3 Algae in Biotic Associations

3.1 Algae in Food Webs

Algae as Sources of Dissolved Organic Material and Detritus

Text Box 3.1 Stable Isotopes in Food Web Studies



ISBN 978-0-9863935-3-2

Algae, Third Edition (Ver. 3.3) Graham, Graham, Wilcox, & Cook

Herbivores

- Flagellates
- Amoebae

Ciliates

Herbivorous rotifers and crustaceans

Algal Food Quality

Algal Defenses Against Herbivory

Structural defenses

Bioluminescence as an herbivory defense

Chemical deterrents and toxins

Neurotoxins.

Hepatotoxins.

Cytotoxins.

3.2 Algae in Symbiotic Associations

Parasites and Pathogens of Algae

Viral pathogens

Bacterial pathogens

Protistan parasites

Fungal parasites

Algal defenses against pathogens

Algae as Parasites or Pathogens

Algae as Epibionts

Algae in Mutualistic Symbioses

Bacterial associations

Fungal associations

Animal Associations

Plant associations

4 Technological Applications of Algae

4.1 Algae as Research Tools

Algal Culture Collections Algal "Omics"

4.2 Algae as Environmental Monitors Algal Bioassays

Algae as Paleoecological Indicators

4.3 Algae as Sources of Food and Other Products Uses of Algae in Aquaculture and as Human Food

Microalgae grown for food or food additives

Macroalgae harvested or grown as food

Gelling Agents from Seaweeds

Alginates

Carrageenan, agar, and agarose

Pharmaceuticals from Algae

Algae as Sources of Biofuels

Text Box 4.1 Hydrogen Production by Algae

- 4.4 Algae in Wastewater Treatment
- 4.5 Genetic Engineering of Algae

5 Algal Diversity and Relationships

5.1 Supergroups and Species Concepts

Species Concepts

Biological species concept

Morphological species concept

Phylogenetic species concept

5.2 Algal Phylogeny

Algae and the Tree of Life Concept

HGT in cyanobacteria

HGT in eukaryotic algae

Molecular Phylogenetic Approaches

RFLPs

RAPDs

AFLPs

Microsatellite DNA/simple sequence repeats (SSRs)

Molecular markers for species- and higher-level phylogeny reconstruction

Generating and Evaluating Phylogenetic Trees

5.3 The Application of Phylogeny

Evolutionary Process

Application in Classification

Ecological Applications

Environmental genomics

Monitoring harmful algae

6 Cyanobacteria

6.1 Structure, Motility, and Photosynthesis Body Types Structure of Photosynthetic Cells of Cyanobacteria and Motility Mechanisms

- Mucilage
- Cyanobacterial cell wall
- Cytoplasmic features
- Photosynthetic Pigments in Light-Harvesting Systems
 - Chlorophylls
 - Phycobilins
 - Carotenoid pigments
- **Chromatic Acclimation**
- **Anoxygenic Photosynthesis**
- **Carbon Fixation and Heterotrophic Growth**
- 6.2 Reproduction
- 6.3 Nitrogen Fixation
- 6.4 Cyanobacteria of Extreme Habitats

6.5 Evolution and Diversity

- The Fossil History of Cyanobacteria
- Phylogeny and Diversity of Modern Cyanobacteria
 - Unicellular and colonial forms lacking specialized cells or reproductive processes
 - Filamentous cyanobacteria lacking spores, heterocytes, or akinetes
 - Exospore-producing cyanobacteria
 - Baeocyte- (endospore-) producing cyanobacteria
 - Heterocyte and akinete-producing cyanobacteria
 - True-branching cyanobacteria

7 Endosymbiosis and the Diversification of Eukaryotic Algae—With a Focus on Glaucophytes and Chlorarachniophytes

7.1 Origin of Eukaryotic Algae

Fossil Evidence for Early Events in the Diversification of Eukaryotic Algae Molecular Evidence Bearing on the Origin of Eukaryotic Cells and Mitochondria The Origin of Plastids

7.2 Endosymbiosis in the Modern World

Prokaryotic Endosymbionts

Cyanobacterial endosymbionts

Eukaryotic Algal Endosymbionts

Marine hosts having eukaryotic endosymbionts

Freshwater hosts having eukaryotic endosymbionts

Kleptoplastids

7.3 Primary Endosymbiosis, with a Focus on the Glaucophyta

Issues Concerning Primary Endosymbiosis

A Focus on the Glaucophyta

Diversity of glaucophytes

7.4 Secondary Endosymbiosis with a Focus on Chlorarachniophytes

Nucleomorphs as Evidence of Secondary Endosymbiosis

Apicomplexan Plastids

Secondary Green Plastids Arose More Than Once

Secondary Red Plastids Arose More Than Once

Diversity of Chlorarachniophytes

7.5 Tertiary Endosymbiosis

8 Euglenoids

8.1 Euglenoid Relationships and Evolutionary History

Euglenoid Cellular Features Reveal Close Relationship to Other Members of Supergroup Excavata

Cellular Features That Distinguish Euglenoids

Euglenoid Diversification

Early bacteria-consuming euglenoids Plastidless, osmotrophic euglenoids Euglenoids that consume eukaryotic prey

Plastid-bearing euglenoids

8.2 Euglenoid Reproduction

8.3 Euglenoid Plastids and Light-Sensing Systems

- 8.4 Euglenoid Ecology
- 8.5 Euglenoid Diversity

9 Cryptomonads

- 9.1 Cryptomonad Relationships
- 9.2 Cryptomonad Mobility and Cellular Structure

Flagella, Cytoskeleton, and Light-Sensing System

Periplast

Ejectisomes and Mitochondria

Plastids and Photosynthetic Pigments

- 9.3 Cryptomonad Reproduction
- 9.4 Cryptomonad Ecology

Nutrition

Temperature and Light as Factors in Cryptomonad Distribution Kleptoplastidy

9.5 Representative Diversity of Cryptomonads

10 Haptophytes

10.1 An Overview of Haptophyte Relationships

10.2 Haptophyte Cellular Structure

Haptonema

Scale Formation and Deposition

Organic scales

Coccoliths

Plastids and Photosynthetic Pigments

10.3 Cell Division

Events Preceding Nuclear Division Nuclear Division and Cytokinesis

10.4 Sexual Reproduction and Life Cycles

10.5 Haptophyte Ecology

Haptophytes in Food Webs

Toxin-Producing Haptophytes

Biogeochemical Impacts of Haptophytes

10.6 Haptophyte Fossil Record

10.7 Diversity of Living Haptophytes

Pavlovophyceae

Coccolithophyceae

Phaeocystales

Prymnesiales

Isochrysidales

Other coccolithophorids

11 Dinoflagellates

11.1 Defining Features and Evolutionary Relationships

Fossil Record

Relationships of Living Dinoflagellates

11.2 Dinoflagellate Cell Biology

Features Commonly Found in Dinoflagellate Cells

Surface features

- Defensive projectiles
- Flagella and motility

Dinokaryon

Mitosis and cytokinesis

Cellular Features of Particular Dinoflagellates

- Prey-capture adaptations
- Scintillons and bioluminescence
- Plastids and photosynthesis
- Eyespots and phototaxis

11.3 Sexual Reproduction and Cyst Formation

Sexual Reproduction

Cysts

11.4 Ecology

Nutrition

Impact of Turbulence

Bloom Formation

Toxin Production

Text Box 11.1 A Dinoflagellate Toxin and Its Antidote

Symbiotic Associations

11.5 Dinoflagellate Diversity

- Noctilucales
- Gymnodiniales
- Prorocentrales
- Peridiniales

Suessiales

Dinophysiales

Gonyaulacales

12 Photosynthetic Stramenopiles I—Diatoms, Pelagophytes, and Silicoflagellates

12.1 Introduction to Photosynthetic Stramenopiles

Relationships of Photosynthetic Stramenopiles

Cellular Features

12.2 Diatoms Diatom Evolutionary History

Cell Division and Frustule Development

Mitosis and cytokinesis

Frustule development

Sexual Reproduction

Diatom Motility and Mucilage Secretion

Diatom Spores and Resting Cells

Ecology and Nutrition

Inorganic nutrients

Organic nutrition

Diatom Collection, Identification, and Diversity

Centric diatoms

Araphid pennate diatoms

Raphid pennate diatoms

12.3 Pelagophytes

12.4 Dictyochophytes

Silicoflagellates Pedinellids

13 Photosynthetic Stramenopiles II—Chrysophyceans, Synurophyceans, and Eustigmatophyceans

13.1 Chrysophyceans

Chrysophycean Stomatocysts

Chrysophycean Ecology

Mixotrophy

Bloom formation

Chrysophycean Diversity

13.2 Synurophyceans

Synurophycean Cell Biology

Flagella and flagellar roots

Silica scale structure, development, and deployment

Synurophycean Reproduction and Ecology

Synurophycean Diversity

13.3 Eustigmatophyceans

Eustigmatophycean Diversity

Pinguiophyceae

14 Photosynthetic Stramenopiles III—Raphidophyceans, Xanthophyceans, Phaeophyceans, and Close Relatives

14.1 Relationships of Raphidophyceans, Brown and Yellow-Green Algae

Schizocladiophyceae

Chrysomerophyceae

Phaeothamniophyceae

Aurearenophyceae

14.2 Raphidophyceans

Raphidophycean Diversity

14.3 Xanthophyceae

Xanthophycean Cell Biology

Xanthophycean Reproduction

Xanthophycean Diversity

14.4 Phaeophyceans (Brown Algae)

Phaeophycean Cell Biology

Cell walls

Plastids and photosynthetic reserve products

Physodes

The cytoskeleton and cell division

Growth Modes and Meristems

Reproduction

Flagellate reproductive cells

Gametangia and parthenogenesis

Pheromones and mating

Sporophyte function

Alternation of generations

Exceptions to alternation of generations

Phaeophycean Diversity and Systematics

Dictyotales

Sphacelariales

Desmarestiales

Sporochnales

Ectocarpales

Laminariales

Alariaceae.

Costariaceae.

Laminariaceae/Lessoniaceae.

15 Red Algae

15.1 Evolutionary History of Red Algae

Fossil Red Algae

Molecular Phylogenetics and Red Algal Systematics

15.2 Red Algal Cell Biology

Extracellular Matrix

Microfibril components of the extracellular matrix

Sulfated polygalactans and mucilages

Calcium carbonate and protein

Plastids, Pigments, and Photosynthetic Storage

Absence of Centrioles, Flagella, and Swimming Motility

15.3 Cell Division, Pit-Plug Formation, and Development

Cell Division

Pit-Plug Formation

Cell Elongation and Repair

Development of Multinucleate Cells and Polyploid Nuclei

15.4 Body Organization of Red Algae

15.5 Reproduction and Life Histories of Red Algae

Asexual Reproduction

Sexual Reproduction

Spermatangia and spermatia

Carpogonia and fertilization

Postfertilization Development and Life History in Bangiophytes

Postfertilization Development and Triphasic Life History of Florideophytes

Carposporophyte development

Tetrasporophytes and tetraspore production

Isomorphic and Heteromorphic Alternation of Florideophyte Generations

15.6 Red Algal Physiology and Ecology

Carbon Metabolism

Red Algal Parasites

Responses to Drought and Osmotic Stress

Ecology of Red Algae

Marine red algae

Freshwater red algae

15.7 Diversity of Red Algae

Cyanidiophyceae

Rhodellophyceae

Porphryridiophyceae

Compsopogonaceae

Bangiophyceae

Florideophyceae

Hildenbrandiophycidae

Hildenbrandiales

Nemaliophycidae

Palmariales

Batrachospermales

Corallinophycidae

Corallinales

Rhodymeniophycidae

Gigartinales

Gelidiales

Gracilariales

Rhodymeniales

Ceramiales

16 Green Algae I—Introduction and Prasinophytes

Part I-Introduction to the Green Algae

16.1 Green Algal Relationships

Unifying Features of the Green Algae Plastids Photosynthetic pigments and light-harvesting complexes

16.2 The Major Green Algal Lineages

Streptophyta

Chlorophyta

Green Algal Body Diversification

Part II—Prasinophytes

16.3 Cellular Features of Prasinophytes

Flagella, Flagellar Apparatus, and Cytoskeleton

Cell Covering and Defensive Extrusomes

Plastids, Pigments, and Light-Harvesting Complex Proteins

Cell Division Asexual and Sexual Reproduction

16.4 Prasinophyte Diversity

17 Green Algae II—Trebouxiophyceans

17.1 General Features of Trebouxiophyceae

- Diversity of Trebouxiophyceans
 - Chlorellales
 - Prasiolales
 - Microthamniales
 - Botryococcus clade
 - Trebouxiales

18 Green Algae III—Ulvophyceans

18.1 General Characteristics, Relationships, and Fossil History of Ulvophyceans

- **Characteristics of Ulvophyceans**
- **Relationships of Ulvophyceans**
- Ulvophycean Fossil History

18.2 Ulvophycean Diversity and Ecology

- **Ulotrichales and Ulvales**
- Trentepohliales
- Cladophorales/Siphonocladales
- Caulerpales
- Uniaxial versus multiaxial body structure
- Wound healing in caulerpaleans
- Cell wall chemistry and plastids

Reproduction

- **Relationships and diversity**
 - Bryopsidineae.
 - Halimedineae
- Dasycladales

19 Green Algae IV—Chlorophyceans

19.1 Chlorophycean Relationships

19.2 General Features of Chlorophyceans

Chlorophycean Body Types

Chlorophycean Asexual Reproduction, Sexual Reproduction, and Life Cycle

Cell Division Features

19.3 Chlorophycean Diversity

Sphaeropleales

Chlamydomonadales, aka Volvocales

Asexual reproduction of Chlamydomonas

Sexual reproduction in Chlamydomonas

Colonial swimming forms

Colonial nonmotile relatives of Volvox

Oedogoniales

Chaetophorales

20 Green Algae V—Streptophyte Algae (Charophyte Algae, Charophyceans)

20.1 General Features and Classification of Streptophyte Algae

Classification of Streptophyte Algae

Streptophyte Algal Orders and Their Evolutionary Significance

20.2 Streptophyte Algal Diversity

Mesostigmales

Chlorokybales

Klebsormidiales

Zygnematales + Desmidiales

Cell biology of Zygnematales Cell walls and mucilage. Mitosis and cytokinesis of zygnemataleans.

Reproduction in Zygnematales

Asexual reproduction.

Sexual reproduction.

Ecology of Zygnematales

Diversity of Zygnematales

Overview of Desmidiales (placoderm desmids)

Cell wall structure, mucilage extrusion, and cell motility of Desmidiales

Mitosis and development of new semi-cells in Desmidiales

Reproduction in Desmidiales

Ecology of Desmidiales

Diversity of Desmidiales

Coleochaetales

Structure and development of Coleochaetales

Cell biology of Coleochaetales

Asexual reproduction in Coleochaetales

Sexual reproduction in Coleochaetales

Ecology of Coleochaetaleans

Charales

Charalean vegetative structure

Reproduction of charaleans

Charalean diversity

21 Phytoplankton Ecology

21.1 Size and Scale in Phytoplankton Ecology Size in Phytoplankton Ecology

Scale in Phytoplankton Ecology

21.2 The Physical Environment

Water as a Fluid Medium

Light and Heat

Water Motions and Phytoplankton Populations

21.3 The Chemical Environment

Salinity and Dominant Ions of Lakes and Oceans

- Carbon
- Nitrogen
- Silicon

Phosphorus

Micronutrients and Colimitation

21.4 Growth Processes of Phytoplankton Populations

Exponential and Logistic Growth

Growth and Light

Question Box 21.1 Working with the Exponential and Logistic Equations

Growth and Nutrient Uptake

Nutrient Uptake

Internal Nutrient Stores

Growth and External Nutrient Supply

Question Box 21.2 Working with the Michaelis-Menten, Droop, and Monod Models of Nutrient Uptake and Growth

21.5 Loss Processes

Perennation

Mortality and Washout

Parasitism

Sedimentation

Swimming and buoyancy

Sinking

Question Box 21.3 Working with the Ostwald Modification of Stokes' Law

Competition

Lotka-Volterra model

A mechanistic model of competition

Question Box 21.4 Working with the Mechanistic Model of Competition

Spatial heterogeneity, disturbance, and coexistence

Grazing

Food webs in the oceans

Food webs in freshwaters

Measuring algal grazing in crustaceans

Trophic cascades and biomanipulations

21.6 Phytoplankton and Global Climate Change

Answers to Question Box Practice Problems

22 Macroalgal and Periphyton Ecology

Part I—Marine Macroalgal Ecology

22.1 Physical Factors and Macroalgal Adaptations

Tides

Waves and Currents

Light

Text Box 22.1 Fluorescence Methods for Assessing Photosynthetic Competency and Nitrogen Limitation

Salinity and Desiccation

Nutrients

22.2 Biological Factors and Macroalgal Adaptations

Herbivore Interactions

Competition

The Ecological Roles of Pathogens

22.3 Macroalgal Biogeography

Tropical Seaweeds

Cold Temperate and Polar Seaweeds

Seaweed Migration

Effects of Pollution and Overfishing on Macroalgae

Algae and coral reefs

Kelp forests

Global Environmental Change

- Part II—Marine Turf-Forming Periphyton
- Part III—Freshwater Periphyton
- 22.4 The Influence of Physical Factors on Periphyton

22.5 The Influence of Biological Factors on Periphyton Grazing

Shoreline Vegetation

- 22.6 Temporal and Spatial Variation
- 22.7 Pollution Effects

23 Terrestrial Algal Ecology

23.1 Soil Algae

Soil Algae in Arid and Semiarid Ecosystems

Composition of biological soil crusts

Adaptations and distribution of biological crust organisms

Adaptations to hot and dry conditions Adaptation to high irradiances

BSC stratification

Ecological functions of biological soil crusts

Soil stabilization Soil enrichment Effects on vascular plants

Disturbances and management

Grazing Mechanical disturbance Management

Soil Algae in Polar Ecosystems

23.2 Cryophilic Algae

Snow Algae

Ice Algae

23.3 Subaerial Algae

Lithic Algae

Lithic algae in cold deserts

Epilithic algae

Epilithic lichens

Hypolithic algae

Chasmolithic algae

Endolithic algae and lichens

Lithic algae in temperate and tropical ecosystems

Lithic algae in hot and temperate deserts

Lithic algae on human constructions

Epiphytic Algae

Epiphytic associations and nitrogen fixation

Glossary

Literature Cited