SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

QUANTIFICATION

A. Approaches

Enumeration	Counting Unit	Reporting Unit
Total cells	1 cell	cells/ml
Natural unit	cells/colonies	units/ml
Areal standard units	400 μm^2	units/ml (not recommended, NY only)

B. Precision/Accuracy

-Assume random distribution of units on counting area.

-If assume Poisson distribution, counting 100 units yields 20% C.I.

-If assume Poisson distribution, counting 400 units yields 10% C.I.

-Everyone counts differently, for different reasons.

-Standard methods suggests counting until reaching at least 100 of dominant species.

-Lund et al. (1958) suggest 100 total units is sufficient (leaves a lot out of assemblage).

-Most counting error comes from field sampling and sample handling rather than from counter (at least for total numbers) once counter is experienced.

-Some workers recommend counting until successive fields or strips yield no significant (P=0.90) change in ratio of numbers among species, rather than to specific number of cells or fields/passes. Others suggest a combination of estimation of counting error and numerical limit.

-Comparing data using different counting methods can be VERY complicated and sometimes impossible (e.g. counted in combination of Natural Unit and Cells versus counted in all Natural Units or all Cells).

C. Actual Counting

-Must establish area of count: fields, passes or strips, whole sample.

-Must establish boundary conditions; can over count if count every cell or colony that is partially in field. Compensate by only counting cells that are partially in upper half of field, or only partially in upper and right boundaries.

-Must establish tally criteria: usually best to count only "live" cells or at least separate live and dead cells.

-Must establish best magnification(s) for your samples. 100X (large filaments, 1+ mm), 200X (>7-10 µm cells or colonies), 400X (<7-10 µm cells or colonies), 1000X (initial identifications and some diatom samples). Based also on particulate level and optics.

D. Biovolume/Biomass Estimates

-At counting level, estimate biovolume by approximating geometric figures for cell and colony shapes to first get a volume based on protoplasm. At same time, one can measure additional dimensions to calculate Natural Unit volume and area as well.

- -simple geometric figures: sphere, cylinder, prolate ellipsoid, rectangular box
- -more complex figures: elliptic prism, rhomboid prism, gomphonemoid, oblate prolate ellipsoid, triangular prism, cymbelloid, screw, cone, truncated cone, spool, custom calculations and combinations of any and all of the above.
- -simple example: Chlamydomonas-sphere
- -complex example: Ceratium-oblate prolate ellipsoid+1 large truncate cone+ 2 medium cones+1 large cone.

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

QUANTIFICATION

-Measure for biovolume (protoplasm exclusive of sheath and spines/setae or dead space) or volume (protoplasm inclusive of sheaths and dead space but exclusive of spines/setae).

-Measure appropriate cell dimensions on a representative number of cells or colonies in sample (20-30, generally).

-Convert biovolume to biomass assuming a density of 1.000 (from μm^3/mL to mg/L=$1*10^{-6}$).

-Can also convert to carbon (mg/L, protoplasm exclusive of sheath, spines/setae, dead space or vacuoles).

-GALD: Greatest Axial Linear Dimension; can often estimate other dimensions from species specific ratios, allowing faster measurement. GALD gives an estimate of edbility. Anything in the plankton greater than >20-30 µm are considered not easily eaten by a Daphnia.

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

SELECTED SOURCES ON ALGAL METHODS

Aloi, J. E. 1990. *A critical review of recent freshwater periphyton field methods*. Canadian Journal of Fisheries and Aquatic Sciences 47:656-670.

Andersen, R.A. (Editor) 2005. *Algal Culturing Techniques*. Elsevier Academic Press, New York, NY 578pp.

Barber, H.G. and Haworth, E.Y. 1981. *A Guide to the Morphology of the Diatom Frustule*. Publication Number 44, Freshwater Biological Association, Titus Wilson & Son, Ltd. 112pp.

Becker, E.W. 1994. *Microalgae: Biotechnology and Microbiology*. Cambridge Studies in Biotechnology 10, 293pp.

Clesceri, L., Greenberg, A.E. and Eaton, A.D. (Editors) 1999. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition, American Public Health Association, Washington, DC.

Coulon, C. and Alexander, V. 1972. *A Sliding-Chamber Phytoplankton Settling Technique for Making Permanent Quantitative Slides with Applications in Fluorescent Microscopy and Autoradiography*. Limnology and Oceanography 17:149-152.

Crumpton, W.G. 1987. *A Simple and Reliable Method for Making Permanent Mounts of Phytoplankton for Light and Fluorescence Microscopy*. Limnology and Oceanography 32:1154-1159.

Crumpton, W.G. and Wetzel, R.G. 1981. *A Method for Preparing Permanent Mounts of Phytoplankton for Critical Microscopy and Cell Counting*. Limnology and Oceanography 26:976-980.

Dodd, J.J. 1987. *The Illustrated Flora of Illinois: Diatoms*. Southern Illinois University Press, Carbondale, IL.

Eaton, A.D., Clesceri, L.S., Rice, E.W. and Greenberg, A.E. (Editors) 2005. *Standard Methods for the Examination of Water and Wastewater*. 21st Edition. American Public Health Association, Washington, DC.

Friedl, T., Day, J. and Preisig, H. (Editors) 2004 *Culture collections of Algae: Increasing Accessibility and Exploring Algal Biodiversity*. Nova Hedwigia Hauptbände, Band 79, Heft 1-2, J. Cramer, Stuttgart 327pp.

Hillebrand, H., et al. 1999. *Biovolume calculation for pelagic and benthic microalgae*. Journal of Phycology 35:403-424.

Kallenbach, E. 1986. *The Light Microscope: Principles and Practice for Biologists*. Charles C. Thomas, Publisher, Springfield, IL. 58pp.

Lin, Shundar. 2001. *Water and Wastewater Calculations Manual*. McGraw-Hill, New York, NY.

Lund, J.W.G., Kipling, C. and LeCren, E.D. 1958. *The Inverted Microscope Method of Estimating Algal Numbers and the Statistical Basis of Estimations by Counting*. Hydrobiologia 11:143-170.

Olrik, K., et. al. 1998. *Methods for Quantitative Assessment of Phytoplankton in Freshwaters*. Part I, Naturvårdsverket, Stockholm.

Porter, S.D., Cuffney, T.F., Gurtz, M.E. and Meador, M.R. 1993. *Methods for Collecting Algal Samples as Part of the National Water Quality Assessment Program*. USGS Open File Report 93-409, United States Geological Survey, Raleigh, NC.

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

SELECTED SOURCES ON ALGAL METHODS

Richardson, J.H. 1991. *Handbook for the Light Microscope: A User's Guide*. Noyes Publications. Park Ridge, NJ 522pp.

Richmond, A. (Editor) 2004. *Microalgal Culture: Biotechnology and Applied Phycology.* Blackwell Publishing, Cornwall, UK 566pp.

Sournia, A. 1978. *Phytoplankton Manual*. Unesco 337pp.

Stein, J.R. 1979. *Handbook of Phycological Methods: Culture Methods & Growth Measurements*. Cambridge University Press, New York, NY 448pp.

Stevenson, J. and Stoermer, E.F. 1981. *Quantitative Differences Between Benthic Algal Communities Along a Depth Gradient in Lake Michigan*. Journal of Phycology 17:29-36. NOTE: Includes method for staining, vapor substitution (toluene) and mounting of diatom cells without previous clearing.

Weber, C.I. 1966. *Methods of collection and analysis of plankton and periphyton samples in the water pollution surveillance system*. FWPCA, Cincinnati, OH 27pp.

Weitzel, R.L. (Editor) *Methods and Measurements of Periphyton Communities: A Review.* ASTM Special Technical Publication 690. American Society for Testing and Methods, Philadelphia, PA.

Wetzel, R.G. and Likens, G.E. 1991. *Limnological Analyses*. 2nd Edition, Springer-Verlag, New York, NY 391pp.

Wheeler, P. 1999. *Cell geometry revisited: Realistic shapes and accurate determination of cell volume and surface area from microscopic measurements*. Journal of Phycology 35:209-210.

Young, R. A. 2005. *Determining the Economic Value of Water. Concepts and Methods*. Resources for the Future, Washington, DC 357pp.

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

SELECTED SOURCES ON ALGAL METHODS

Media	Refractive Index (n)	Solvent	Comments	Manufacturer/ Supplier
Natural Media				
Canada Balsam	1.53	Xylene, benzene toluene, trichloroethylene, dioxan	Yellows with age, bleaches stains; dries slowly but can be combined with other resins to remedy this.	(not proprietary)
Dammar Balsam	1.53	Xylene, benzene	Superior to Canada Balsam; faster drying if dissolved in benzene.	(not proprietary)
Karo (mixture of dextrose, dextrin, maltose)	?	Water, alcohol	Hardens so that no sealing is necessary except in moist climates.	(not proprietary)
Synthetic media				
Carmount 165	1.63-1.64	Xylene or toluene		Cargille Labs, Inc.
Clearax	1.67	Xylene, acetone	Good for diatoms	No longer commercially available
Clearmount	1.51	Xylene, benzene, toluene, alcohol, dioxan	Conserves stains	No longer commercially available
CMCP-10		Water, alcohol	Dries quickly but stains fade	Electron Microscopy Sciences
Cumar R-9, 11	1.63	Toluene	Dark orange	Neville Chemical Co.
Euparal	1.48	Xylene, alcohol	Mixture of natural and synthetic resins; can use directly after 95% alcohol; intensifies haematoxylin stains	BioQuip
Glycerine Jelly	1.47	Water	Semi-permanent; store slides flat; sealing mandatory. Add 1 g phenol crystals to 100 g jelly for stock solution	(not proprietary)

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

SOME MOUNTING MEDIA IN GENERAL USE

(ADAPTED FROM SOURNIA, 1978)

Media	Refractive Index (n)	Solvent	Comments	Manufacturer/ Supplier
HPMA	1.5	Water	Clears nitrocellulose filters and seals permanently	SPI Supplies OR Electron Microscopy Sciences
Hyrax	1.63	Xylene, benzene, toluene	Very expensive; good for diatoms	No longer commercially available
Lakeside Cement #70C	1.54	Alcohol (EtOH)	Slightly yellow	Lakeside Products
Meltmount	1.7	Xylene or toluene	Easy to use	McCrone Group
Naphrax	1.72	Xylene, benzene, acetone	Good for diatoms.	Naphrax, LTD.
Permount	1.53+	Toluene	Conserves stains; does not yellow	Fisher Scientific
Pleurax	1.75	Alcohol	Good for delicate diatoms	US: Prof Dailey, Upenn
Zyax	1.7	Toluene/Xylene	Good for delicate diatoms	US: Prof Dailey, Upenn

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

MANUFACTURERS OF RESINS

BioQuip
2321 Gladwick Street
Rancho Dominguez, CA 90220
310-667-8800
http://www.bioquip.com/

Cargille Labs, Inc.
55 Commerce Road
Cedar Grove, NH 07009
973-239-6633
www.cargille.com

Custom Research and Development Inc.
Former maker of Hyrax
(Out of business as of 1/1/94)

Electron Microsocpy Sciences
1560 Industry Road
PO Box 550
Hatfield, PA 19440
215-412-8400
www.emsdiasum.com

Fisher Scientific Company
711 Forbes Avenue
Pittsburgh, PA 15219
800-766-7000
https://www.fishersci.com/us/en/home.html

Lakeside Microscope Accessories
26749 S. Governors Highway
Monee, IL 60449
708-534-8400
http://www.lakeside-products.com/

McCrone Accessories and Components
850 Pasquinelli Drive
Westmont, IL 60559
630-887-7100
https://www.mccrone.com

Naphrax, Ltd.
40 High Street
Harrold
Bedfordshire MK43 7DQ
United Kingdom
44 0 1234 7213837
Mr.pjkelly@gmailcom

Neville Chemical Company
800 Neville Rd
Pittsburgh, PA 15225
412-331-4200
http://www.nevchem.com/

SPI Supplies
206 Garfield Ave,
West Chester, PA 19380-4512
800-242-4774 or 610-436-5400
http://www.2spi.com/

Professor William Dailey
University of Pennsylvania
dailey@sas.upenn.edu

Hyrax recipe
Hanna, G.D. 1930. Hyrax, a new mounting medium for diatoms. J. Royal Microsc. Soc. 50:424-426.

Pleurax recipe
Hanna, G.D. 1949. A Synthetic Resin Which Has Unusual Properties. J. Royal Microsc. Soc. Series 3. 69(1):25-28.

SUPPLEMENT #1: FRESHWATER ALGAL METHODOLOGY

EQUIPMENT SUPPLIERS

Company	Telephone #	Website	Primary Types of Supplies
Aquatic Research Instruments	800-320-9482	**www.aquaticresearch.com**	Field samplers, lab supplies
Ben Meadows	800-241-6401	**www.benmeadows.com**	Field equipment, lab supplies
Carolina Biological Supplies	800-334-5551	**www.carolina.com**	Lab supplies, specimens
Cole Parmer	800- 323-4340	**www.coleparmer.com**	Lab supplies
Fisher Scientific	800-766-7000	**www.fishersci.com**	Lab supplies
Forestry Suppliers	800-647-5368	**www.forestry-suppliers.com**	Field equipment
Geneq	800-463-4363	**www.geneq.com**	Field and lab supplies
Hach	800-227-4224	**www.hach.com**	Field and lab chemistry supplies
HydroLab		**hydrolab.com**	Field Meters
PhycoTech	269-983-3654	**www.phycotech.com**	Algae-related supplies and support
Thomas Scientific	800-345-2100	**www.thomassci.com**	Lab Supplies
VWR Scientific	800-932-5000	**us.vwr.com**	Lab supplies
Ward's Science	800-962-2660	**www.wardsci.com**	Lab supplies, specimens
Wildlife Supply Company (Wildco)	517-799-8100	**wildco.com**	Field samplers, lab supplies
Yellow Springs Instruments (YSI)	937-688-4255	**www.ysi.com**	Field meters

Microscopes and related supplies: Contact your local dealer. Companies include:

- Leica (which includes Leitz, Reichert, AO Spencer, Bausch and Lomb)
- Nikon
- Olympus
- Zeiss
- Meijer

SUPPLEMENT #2: ALGAL TAXONOMY

North America

- **American Type Culture Collection - ATCC (USA)**
- **Chlamydomonas Genetics Center (USA)**
- **UTEX - The Culture Collection of Algae (USA)**
- **Canadian Phycological Culture Centre (CPCC) (Canada)**

Asia/Australia

- **Microbial Culture Collection-NIES - MCC-NIES (Japan)**

Europe

- **Algobank (France)**
- **Culture Collection of Algae at the University of Cologne - CCAC (Germany)**
- **Sammlung von Algenkulturen - SAG (Germany)**
- **SAMS culture collection of algae and protozoa**

World Federation of Culture Collections *(Not exclusive to Algae)*

SUPPLEMENT #2: ALGAL TAXONOMY

GUIDE TO THE NAMES AND CHARACTERISTICS OF THE FRESHWATER ALGAL GROUPS

Algal taxonomic systems have varied considerably over the last century or even longer, with generally increasing complexity as techniques for seeing or otherwise deciphering algal features have become more sophisticated. Occasionally we get a simplification, as when culturing reveals that two or more previously separate taxa are really the same taxon grown under different conditions. Yet mostly we find new reasons to split groups apart based on physical, chemical, or genetic differences not previously observed or understood. If the split has some ecological meaning, it can be very useful in environmental management work. Even when a single taxon has different growth forms in response to environmental conditions, having different names can be useful. You can always combine data into fewer groups, but you can't separate data that were lumped from the start.

The major groupings of algae have endured for many decades, although whether these are divisions, phyla, classes, orders, or some other taxonomic level designation has varied. We have some well known common names (e.g., diatoms, dinoflagellates) that are easily recognized but may not relate clearly to the taxonomic group name (Bacillariophytes, Pyrrhophytes). But overall, we have general groupings that make sense in light of the major group features: pigments, cell wall, energy storage products, and motility. Reproduction is also a key factor in major groupings, but is less commonly observed in actual sample analysis. Within groups, a lot of subdivisions are based on morphological trends or specialized cell features common to a part of the overall group. Caution must be exercised by those constructing taxonomic systems, however, in discerning features that truly represent a group or subgroup trend, and are not merely responses to environmental conditions that cut across perceived group boundaries. For those identifying algae, it becomes important to learn the visual cues that represent major group features, such as color, cell wall appearance, energy product appearance, flagella number, relative size and placement on the cell, and reproductive structures when present.

The table provided here is intended to provide a framework for dividing algae into major groups. The most recent and perhaps hardest split to understand is the fractionation of golden algae, or Chrysophyta, into at least five groups: chrysophytes, xanthophytes, haptophytes, raphidophytes and eustigmatophytes. In the lectures portion of this workshop, these will be considered collectively, but there is justification, mainly ultrastructural features, for making the split. Older schemes recognized mainly chrysophytes and xanthophytes, and some systems even combined the bacillariophytes with these other groups based on pigment similarity. Algal taxonomy is just not as simple as that of many higher organisms, and you have to learn to accept uncertainty, discrepancy, and change as a fact of life when doing algal taxonomy.

SUPPLEMENT #2: ALGAL TAXONOMY

REFERENCES FOR MAJOR TAXONOMIC GROUPINGS

Bold, H.C. and Wynne, M.J. 1985. *Introduction to the Algae*. 2nd Edition, Prentice-Hall, Englewood Cliffs, NJ 720pp.

Cole, G. 1994. *Textbook of Limnology*. Waveland Press, Inc., Prospect Heights, IL 412pp.

Dodds, W.K. 2002. *Freshwater Ecology*. Academic Press., San Diego, CA 569pp.

Graham, L.E. and Wilcox, L.W. 2000. *Algae*. Prentice-Hall, Englewood Cliffs, NJ 640pp.

John, D.M., Whitton, B.A. and Brook, A.J. 2002. *The Freshwater Algal Flora of the British Isles*. University of Cambridge Press, Cambridge, UK 702pp.

John, D.M., Whitton, B.A. and Brook, A.J. 2011. *The Freshwater Algal Flora of the British Isles*. University of Cambridge Press, Cambridge, UK 878pp.

Kalff, J. 2002. *Limnology*. Prentice-Hall, Upper Saddle River, NJ 592pp.

Lee, R.E. 2008. *Phycology*. 4th Edition. University of Cambridge Press, New York, NY 645pp.

VanDenHoek, C., Mann, D.G. and Jahns, H.M. 1995. *Algae*. University of Cambridge Press, Cambridge, UK 623pp.

Wehr, J.D. and Sheath, R.G. 2003. *Freshwater Algae of North America.* Academic Press, New York, NY 918pp.

Wehr, J.D., Sheath, R.G. and Kociolek J.P. 2015. *Freshwater Algae of North America*. Academic Press, New York, NY 1050pp.

SUPPLEMENT #2: ALGAL TAXONOMY

Name (Division or Class)	**Common Name**	**Common Aquatic Habitat**	**Common Morphology/Motility**	**Cell Wall**	**Primary Pigments/Color**	**Energy Storage Product**	**Examples**
Chlorophyta	Green Algae	Oceans, Lakes, Rivers, Estuaries. Planktonic and Attached	Microscopic to visible with the naked eye. Unicellular, colonial and filamentous, includes flagellates – highly variable by subgroup. *Flagella in pairs of equal length.*	Cellulose, glucosides, xylans and mannans or wall absent. Stoneworts calcify. *Walls appear rigid, thick in most cases.*	Chl*a*, Chl*b*, lutein, zeaxanthin, violaxanthin, antheraxanthin neoxanthin *Color = grass green, sometimes masked by other pigments (red.)*	Starch *Pyrenoids usually visible.*	Cladophora, Ulva, Oocystis, Scenedesmus, Pyramichlamys (Tetraselmis), Pandorina, Planctonema, Oedogonium, Spirogyra
Cyanophyta	Blue-green Algae or Cyanobacteria	Lakes, Rivers, Estuaries, Oceans. Planktonic and Attached	Microscopic to visible with the naked eye. Unicellular, colonial and filamentous, some filaments glide or move. *No flagella.*	Mucopeptides or Peptidoglycans (amino sugars + amino acids). *Walls minimally visible, sheath sometimes apparent.*	Chl*a*, phycocyanin, phycoerythrin, allophycocyanin *Color = Blue-green to violet to black.*	Cyanophycean starch, cyanophycean granules, polyphosphate bodies, carboxysomes. *Not obvious or observed as small dots*	Anabaena, Nostoc, Oscillatoria, Lyngbya, Chroococcus, Microcystis, Merismopedia, Aphanocapsa
Bacillariophyta (Bacillariophyceae)	Diatoms or Golden Brown Algae	Lakes, Rivers, Estuaries, Oceans. Planktonic and Attached	Microscopic. Unicellular, colonial and filamentous, some cells stalked, some cells motile by gliding. *Flagella only in gametes.*	Opaline silica (SiO_2). *Walls appear very rigid, thick in most cases.*	Chl*a*, Chlc$_2$,Chl*c*$_1$, Chl*c*$_3$, fucoxanthin *Color = golden brown.*	Chrysolaminarin, lipid, mannitol. *Appears as small droplets in most cases.*	Navicula, Nitzschia, Asterionella, Fragilaria, Cyclotella, Aulacoseira
Chrysophyta (Chrysophyceae)	Golden Algae	Lakes, Rivers, Estuaries, Oceans. Mostly Planktonic	Microscopic. Unicellular, colonial, mostly flagellates. *Flagella usually in pairs of unequal length, but can be single.*	Cellulose or silicified walls sometimes with silica scales or enclosed by mineralized lorica. Some lack distinct cell wall (membrane only). *May appear "fuzzy" from scales.*	Chl*a*, Chl*c*$_1$, Chl*c*$_2$, fucoxanthin *Color = golden to brownish.*	Chrysolaminarin. *Appears as small droplets in most cases.*	Mallomonas, Dinobryon, Erenkenia, Kephyrion, Synura, Chrysosphaerella

SUPPLEMENT #2: ALGAL TAXONOMY

Name (Division or Class)	**Common Name**	**Common Aquatic Habitat**	**Common Morphology/Motility**	**Cell Wall**	**Primary Pigments/Color**	**Energy Storage Product**	**Examples**
Xanthophyta (Xanthophyceae or Tribophyceae)	Yellow-Green Algae	Lakes, Rivers, Estuaries, Oceans. Planktonic and attached	Microscopic. Unicellular, colonial and filamentous. *Few flagella, but where present, pairs unequal in length.*	Cellulose or silicified walls. Some lack distinct cell wall (membrane only). *Usually appear rigid.*	Chl*a*, Chl*c*$_1$, Chl*c*$_2$, vaucheriaxanthin *Color = yellow green.*	Chrysolaminarin. *Appears as small droplets in most cases.*	Tribonema, Gonichloris, Heterothrix, Vaucheria
Haptophyta (Haptophyceae or Prymnesiophyceae)	Yellow Brown Algae or Haptophytes	Lakes, Rivers, Brackish, Estuaries, Oceans. Planktonic	Microscopic. Unicellular, all flagellates. *Flagella in pairs of unequal length, plus a short stiff hair (haptonema).*	Cellulose often covered by organic scales. *"Soft" or "fuzzy" appearance.*	Chl*a*, Chl*c*$_1$, Chl*c*$_3$, fucoxanthin, ß-carotene *Color = yellow brown to golden brown.*	Chrysolaminarin, paramylon (Van Den Hoek). *Appears as small droplets in most cases.*	Chrysochromulina, Prymnesium
Raphidophyta (Raphidophyceae)	Raphidophytes	Lakes, Ponds, Acid Bogs, Rivers. Planktonic	Microscopic. Unicellular, all flagellates. *Only one flagellum usually evident, but shorter one present.*	Thick periplast with small muciferous bodies or trichocysts embedded. *Cell wall not very obvious, appears flexible.*	Chl*a*, Chl*c*$_1$, Chl*c*$_2$, ß-carotene, diadinoxanthin, vaucheriaxanthin, heteroxanthin *Color = yellow-green to green.*	Lipid. *Appears as small droplets in most cases.*	Gonyostomum
Eustigmatophyta (Eustigmatophyceae)	Eustigmatophytes	Lakes, Ponds, Acid Bogs, Rivers. Mostly Planktonic	Microscopic. Unicellular, includes flagellates. *Flagella in pairs of unequal length.*	Unknown cell wall. *Wall not visibly distinct in most cases.*	Chl*a*, violaxanthin, ß-carotene, Vaucheriaxanthin *Color = green to yellowish green.*	Unknown storage product, chrysolaminarin (?) *Appears as small droplets in most cases.*	Vischeria, Ellipsoidon
Pyrrhophyta	Dinoflagellates	Oceans, Lakes, Rivers, Estuaries. Mostly planktonic, some attached or epizootic.	Microscopic. Unicellular or small chains, mostly flagellates. *Two flagella, one wraps around middle of cell, other trails cell.*	Cellulose (when present) and polysaccharides, often thick thecal plates present. *Thecate forms appear rigid and heavy, naked forms appear more flexible.*	Chl*a*, Chl*c*$_1$, Chl*c*$_2$, ß-carotene, peridinin, fucoxanthin, diadinoxanthin *Color = red to brown, some colorless.*	Starch, lipid. *Cell contents tend to be dense, looking like a lot of lumps, some of which are storage products.*	Peridinium, Ceratium, Glenodinium, Gymnodinium

SUPPLEMENT #2: ALGAL TAXONOMY

Name (Division or Class)	**Common Name**	**Common Aquatic Habitat**	**Common Morphology/Motility**	**Cell Wall**	**Primary Pigments/Color**	**Energy Storage Product**	**Examples**
Cryptophyta	Cryptomonads	Oceans, Lakes, Rivers, Estuaries. Mostly planktonic.	Microscopic. Unicellular. All flagellates. *Two flagella, subequal length.*	Periplast (trilaminate plasmalemma) often with ejectosomes. *Walls generally appear thin and flexible.*	Chl*a*, Chl*c*$_2$, phycocyanin, phycoerythrin, ∀-carotene, alloxanthin *Color = blue to red to brown, some colorless.*	Starch, lipid. *Pyrenoid-like structures are often evident.*	Cryptomonas, Rhodomonas, Chroomonas
Euglenophyta	Euglenoids	Oceans, Lakes, Rivers, Estuaries. Mostly planktonic, some epizooic.	Microscopic. Unicellular. All flagellates except for epizooic taxa. *Only one flagellum usually evident, but shorter one present.*	Plasmalemma exterior, pellicle just underneath with helical organization. Some species with a pectin lorica often mineralized with iron or magnesium. *Appearance varies widely with genus.*	Chl*a*, Chl*b*, ß-carotene, neoxanthin, diadinoxanthin *Color = red to green, some Trachelomonas appear brown from iron in the lorica.*	Paramylon. *Paramylon bodies usually evident; various shaped rods or rings.*	Euglena, Trachelomonas, Astasia, Colacium, Phacus.
Rhodophyta	Red Algae	Oceans, Rivers, Lakes, Estuaries. Mostly attached and some Planktonic.	Microscopic to visible with the naked eye. Unicellular, colonial and filamentous. *Flagella in gametes only.*	Cellulose, xylans and mannans, polysaccharides, alginate, some calcify. *Usually very distinct walls, often gelatinous coating.*	Chl*a*, phycoerythrin, phycocyanin, allophycocyanin, ß-carotene, ∀-carotene, zeaxanthin *Color = red-violet to black.*	Floridean starch. *Not visible or evident as small, dark dots.*	Gigartina, Gracilaria, Batrachospermum, Bangia
Phaeophyta	Brown Algae	Oceans, Estuaries, Streams, Lakes, Mostly marine. Mostly attached and some Planktonic.	Microscopic to visible with the naked eye. Unicellular, colonial and filamentous. *Flagella in gametes only.*	Cellulose, alginic acid, sulfated mucopolysaccharides. *Usually very distinct walls, often gelatinous coating.*	Chl*a*, Chl*c*$_1$, Chl*c*$_2$, fucoxanthin *Color = brown.*	Chrysolaminarin, mannitol, lipid. *Appears as small droplets in most cases.*	Laminaria, Sargassum, Ectocarpus

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

(Bolded entries signify the most major and current works usually for one algal division or more specific class or order. Bolded and underlined entries are the most useful single volume, multi-divisional works.)

Anagnostidis, K. and Komárek, J. 1988. *Modern approach to the classification system of Cyanophytes. 3 - Oscillatoriale*s. Algological Studies 50-53: 327-472, Archiv Fur Hydrobiologie, Supplementband 80, Stuttgart.

Anagnostidis, K. and Komárek, J. 1990. *Modern approach to the classification system of Cyanophytes. 5 - Stigonematales*. Algological Studies 59:1-73, Archiv Fur Hydrobiologie, Supplementband 86, Stuttgart.

Anton, A. and Duthie, H.C. 1981. *Use of Cluter Analysis in the Systematics of the Algal Genus Cryptomonas*. National Research Council of Canada.

Archibald, R.E.M. 1982. *Diatoms of South Africa. 1. New Species from the Sundays River* (Eastern Cape Province). Bacillaria, Volume 5.

Bahls, L.L. 2004. *Northwest Diatoms, A Photographic Catalogue of Species in the Montana Diatom Collection.* Volume 1, MO 240pp.

Bahls, L.L. 2005. *Northwest Diatoms, A Photographic Catalogue of Species in the Montana Diatom Collection.* Volume 2, MO 474pp.

Bahls, L.L. 2006. *Northwest Diatoms, A Photographic Catalogue of Species in the Montana Diatom Collection.* Volume 3, MO 478pp.

Baker, P.D. and Fabbro, L.D. 2002. *A Guide to the Identfication of Common Blue-Green Algae (Cyanoprokaryotes) in Australian Freshwaters*. Identification and Ecology Guide No. 25. 2nd Edition, Cooperative Research Centre for Freshwater Ecology.

Barber, H.G. and Haworth, E.Y. 1981. *A Guide to the Morphology of the Diatom Frustule with a Key to the British Freshwater Genera.* Freshwater Biological Association Scientific Publication #44, Ambleside, Cumbria, UK.

Berk, S.G. and Gunderson, J.H. 1993. *Wastewater Organisms A Color Atlas*. CRC Press, Boca Raton, FL 25pp.

Bourrelly, P. 1990. *Les Algues d'Eau Douce*. Tome I. Les Algues Vertes, Second Edition. N. Boubée et Cie, Paris 576pp.

Bourrelly, P. 1981. *Les Algues d'Eau Douce*. Tome II, Les Algues Jaunes et Brunes, Chromophycees, Chrysophycees, Phéophycées, Xanthophycées et Diatomées. Second Edition, N. Boubée et Cie, Paris 517pp.

Bourrelly, P. 1986. *Les Algues d'Eau Douce*. Tome III. Les Algues Bleues et Rouges, Les Eugléniens, Peridiniens et Cryptomonadines. Second Edition, N. Boubée et Cie, Paris.

Camburn, K.E., Kingston, J.C. and Charles, D.F. 1984-1986. *Paleoecological Investigation of Recent Lake Acidification: Diatom Iconograph*. Unpublished Report Series No. 3, PIRLA , Indiana University, Bloomington.

Canter-Lund, H. and Lund, J.W.G. 1995. *Freshwater Algae: Their Microscopic World Explored*. Biopress Ltd., Bristol, England.

Carter, J.R. and Bailey-Watts, A.E. 1981. *A Taxonomic Study of Diatoms from Standing Freshwaters in Shetland*. Nova Hedwigia, Band XXXIII.

Carty, S. 2014. *Freshwater Dinoflagellates of North America* 256pp.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Chaumont, J.-P. & Germain, H. 1976. *Pinnularia superdivergentissima nov. sp., Achnanthes subsalsoides Hustedt var. sterwennensis nov. var*. Bulletin de la Société Botanique de France 123(9): 587-590.

Cole, K.M. and Sheath, R.G. (Editors) 1990. *Biology of the Red Algae*. Cambridge University Press, Cambridge, NY 750pp.

Compere, P. 1986. *Flore Pratique des Algaes D'eau Douce de Belgique. 1. Cyanophyceae*. Jardin Botanique National de Belgique.

Cooper, Vivenne C.1996. *Microalgae Microscopic Marvels*. Riverside Books, Hamilton, NZ 164pp.

Cox, E.J. 1982. *Taxonomic studies on the diatom genus Navicula Bory. IV. Climaconeis Grun., a genus including Okedenia inflexa* (Bréb.) Eulenst, Ex De Toni and Members of Navicula Sect. Johnsonieae Sensu Hustedt, British Phycological Journal 17: 147-168.

Cox, E.J. 1996. *Identification of Freshwater Diatoms from Live Material*. Chapman & Hall 158pp.

Cox, E.R. and Bold, H.C. 1966 Reprint 1977. *Phycological Studies, VII. Taxonomic Investigations of Stigeoclonium*. Otto Koeltz Science Publishers, 167pp.

Croasdale, H.T., Bicudo, C.E.M. and Prescott, G.W. 1983. *A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae, Section 5*. University of Nebraska Press, Lincoln.

Croasdale, H. and Flint, E.A. 1986. *Flora of New Zealand. Freshwater Algae, Chorophyta, Desmids with Ecological Comments on Their Habitats.* Volume I, V.R. Ward, Govt Printer, Wellington, NZ.

Croasdale, H. and Flint, E.A. 1988. *Flora of New Zealand. Freshwater Algae, Chorophyta, Desmids with Ecological Comments on Their Habitats*. Volume II. Botany Division, D.S.I.R. Christchurch, NZ.

Croasdale, H. and Flint, E.A. 1994. *Flora of New Zealand. Freshwater Algae, Chorophyta, Desmids with Ecological Comments on Their Habitats.* Volume III, Manaaki Whenua Press, Lincoln, NZ.

Cronberg, G., Skulberg, O.M. and Willen, T. (Editors) 1994. *Cyanophyta (Cyanobacteria) Morphology, Taxonomy, Ecology and Toxicology*. Algological Studies 75, Archiv. Fur Hydrobiologie, Supplementband 105. Stuttgart.

Cronberg, G. and Annadotter, H. (Editors) 2006. *Manual on aquatic cyanobacteria. A photo guide and a synopsis of their toxicology*. ISSHA and United Nations Educational, Scientific and Cultural Organization, Denmark.

Cumming, B.F., Wilson, S.E., Hall, R.I. and Smol, J.P. (1995). *Diatoms from British Columbia (Canada) Lakes and their relationship to salinity, nutrients and other limnological variables*. Bibliotheca Diatomologica 31: 1-207.

Czarnecki, D.B. and Blinn, D.W. 2006. *Diatoms of Lower Lake Powell and Vicinity (Diatoms of Southwestern USA. I)*. Bishen Sing Mahendra Pal Singh, Dehra Dun, India 119pp.

Desikachary, T.V. 1959. *Cyanophyta*. Indian Council of Agricultural Research, New Delhi 686pp.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Desikachary, T.V. and Prema, P. 1996. *Silicoflagellates* (Dictyochophyceae). Bibliotheca Phycologica, Band 100, J. Cramer, Stuttgart, Germany 83pp.

Dillard., G.E. 1989. *Freshwater Algae of Southern United States. Part 1. Chlorophyceae: Volvocales, Tetrasporales and Chlorococcales*. Bibliotheca Phycologica Vol. 81, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1989. *Freshwater Algae of the Southeastern United States. Part 2. Chlorophyceae: Ulotrichales, Microsporales, Cylindrocapsales, Sphaeropleales, Chaetophorales, Cladophorales, Schizogoniales, Siphonales and Oedogoniales*. Bibliotheca Phycologica Vol 83, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1990. *Freshwater Algae of the Southeastern United States. Part 3. Chlorophyceae: Zynematales: Zygnemataceae, Mesotaeniaceae and Desmidiaceae* (Section 1). Bibliotheca Phycologica Vol 85, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1991. *Freshwater Algae of the Southeastern United States. Part 4. Chlorophyceae: Zygnematales: Desmidiaceae* (Section 2). Bibliotheca Phycologica Vol 89, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1991. *Freshwater Algae of the Southeastern United States. Part 5. Chlorophyceae: Zygnematales: Desmidiaceae* (Section 3). Bibliotheca Phycologica Vol 90, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1993. *Freshwater Algae of the Southeastern United States. Part 6. Chlorophyceae: Zygnematales: Desmidiaceae* (Section 4). Bibliotheca Phycologica Vol 93, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 1999. *Common Freshwater Algae of the United States. An Illustrated Key to the Genera* (Excluding Diatoms). Balogh Scientific Books, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Dillard, G.E. 2000. *Freshwater Algae of the Southeastern United States. Part 7. Pigmented Euglenophyceae*. Bibliotheca Phycologica Vol 106, J. Cramer, Stuttgart, Germany.

Dillard, G.E. 2007. *Freshwater Algae of the Southeastern United States, Part 8. Chrysopyceae, Xanthophyceae, Raphidophyceae, Cryptophyceae and Dinophyceae*. Bibliotheca Phycologica Vol 112, J. Cramer, Stuttgart, Germany.

Dodd, J.J. 1987. *The Illustrated Flora of Illinois: Diatoms*. Southern Illinois University Press, Carbondale, IL.

Duff, K., Zeeb, B. and Smol, J. 1995. *Atlas of Chrysophycean Cysts*. Kluewer Academic Publishers.

Eddy, S. 1930. *The Fresh-Water Armored or Thecate Dinoflagellates*. Transactions of American Microscopical Society, Vol. XLIX, No. 4.

Entwisle, T.J., Sonneman, J.A. and Lewis, S.H. (Editors) 1997. *Freshwater Algae in Australia*. Sainty and Associates Pty. Ltd., Austrialia.

Entwisle, T.J., Skinner, S., Lewis, S.H. and Foard, H.J. 2007. *Algae of Australia Batrachospermales, Thoreales, Oedogoniales and Zygnemaceae*. Csiro Publishing, Melbourne. 191pp.

Ettl, H. 1978. *Xanthophyceae*. Süßwasserflora von Mitteleuropa, Band 3, Teil 1, Gustav Fischer Verlag, Stuttgart.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Ettl, H. 1983. *Chlorophyta I: Phytomonadina.* Süßwasserflora von Mitteleuropa, Band 9, Gustav Fisher Verlag, Stuttgart.

Ettl, H. and Gärtner, G. 1988. *Chlorophyta II: Tetrsporales, Chlorococcales, Gloeodendrales*. Süßwasserflora von Mitteleuropa, Band 10, Gustav Fisher Verlag, Stuttgart.

Ettl, H., Gerloff, J. and Heynig, H. 1980. *Xanthophyceae.* Süßwasserflora von Mitteleuropa, Band 4, Teil 2, Gustav Fischer Verlag, Stuttgart.

Ettl, H., Gerloff, J. and Heynig, H. 1982. *Schizomycetes.* Süßwasserflora von Mitteleuropa, Band 20, Gustav Fischer Verlag, Stuttgart.

Ettl, H., Gerloff, J. and Heynig, H. 1984. *Conjugatophyceae I, Chlorophyta VIII, Zygnemales*. Süßwasserflora von Mitteleuropa, Band 16, Gustav Fischer Verlag, Stuttgart.

Ettl, H., Gerloff, J., and Haynig, H. 1990. *Dinophyceae (Dinoflagellida).* Süßwasserflora von Mitteleuropa, Band 6, Gustav Fischer Verlag, Stuttgart.

Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. 1985. *Chrysophyceae und Haptophyceae*. Süßwasserflora von Mitteleuropa, Band 1, Gustav Fischer Verlag, Stuttgart.

Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. 1999. *Cyanoprokaryota I., Chroococcales*. Süßwasserflora von Mitteleuropa, Band 19/1, Gustav Fischer Verlag Jena 548pp.

Fallu, M.-A., Allaire, N., and Pienitz, R. 2000. *Freshwater Diatoms from northern Québec and Labrador (Canada)*. Bibliotheca Diatomologica, Band 45, Edited by J. Cramer, Gebrüder Borntraeger Verlag Berlin/Stuttgart. 200pp.

Faust, M.A. and Gulledge, R.A. 2002. *Identifying Harmful Marine Dinoflagellates*. Department of Systematic Biology - Biology National Museum of Natural History, Washington, DC 144pp.

Firsova, A.D. and Likhoshway, Y.V. 2006. *Atlas of Chrsophycean Cysts of Lake Baikal*. Nauka, Novosibirsk, 147pp.

Foged, N. 2006. *Diatoms in Alaska*. Bishen Singh Mahendra Pal Singh,. Dehra Dun, India. 317pp.

Friedl, T., Day, J.G. and Preisig, H.R. (Editors) 2004. *Culture Collections of Algae: Increasing Accessibility and Exploring Algal Biodiversity*. Gebruder Borntraeger, Stuttgart, Germany.

George, E.A. 1976. *A Guide to Algal Keys (Excluding Seaweeds)*. British Phycological Journal 11:49-55.

Germain, H. & LeCohu, R. (1981). *Variability of some features in a few species of Gomphonema from France and the Kerguelen Islands (South Indian Ocean).* In Proceedings of the 6th Symposium on Recent and Fossil Diatoms, ed. R. Ross, Kbnigstein, Koeltz Scientific Books, p. 167-77.

Germain, H. 1980. *Trois Nouvelles Diatomées Dans Le Bassin D'une Serre A Angers* (France). Cryptogamie, Algologie, I, 1: 19-27.

Germain, H. 1982. *Navicula Joubaudi Nov. Nom. (Bacillariophyceae)*. Cryptogamie, Algologie III 1: 33-36.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Germain, H. 1982. *Quatre Navicules du Groupe Des Subtilissimae (Diatomophyceae)*. Cryptogamie, Algologie, III, 2: 105-111.

Germain, H. 1986. *Variations Extrêmes Chez Gomphonema olivaceum (Diatomée)*. Cryptogamie, Algologie, 7: 123-128.

Golubic, S., Komárek, J., and Lhotský, O. (Editors). 1985. *Cyanophyta (Cyanobacteria) Morphology, Taxonomy, Ecology*. Algological Studies 38/39, Archiv Fur Hydrobiologie, Supplementband 71, Stuttgart.

Greuter, W. et al. (Editors) 1988. *International Code of Botanical Nomenclature.* Balogh Scientific Books, Champaign, IL.

Hallegraeff, G.M., Anderson, D.M., and Cembella, A.D. 2003. *Manual on Harmful Marine Microalgae*. UNESCO. Paris, France 793pp.

Hansmann, E.W. 1973. *Diatoms of the Streams of Eastern Connecticut.* Bulletin 106. Department of Environmental Protection, Hartford, CT.

Hargreaves, J.W. and Whitton, B.A. 1976. *Effect of pH on Growth of Acid Stream Algae*. British Phycological Journal 11: 215-223.

Hartley, B., Barber, H.G., Carter, J.R., and Sims, P.A. 1996. *An Atlas of British Diatoms.* Biopress Ltd., Bristol, UK 601pp.

Hegewald, E. and Silva, P.C. 1988. *Annotated Catalogue of Scenedesmus and Nomenclaturally Related Genera*, Including Original Descriptions and Figures. Bibliotheca Phycologica Band 80, J. Cramer, Stuttgart. 587pp.

Hemblen, C., Spindler, M, and Anderson, O.R. 1989. *Modern Planktonic Formanifera*. Springer-Verlag, New York, NY 363pp.

Hindák, F. 1962. Systematische *Revision der Gattungen Fusola Snow und Elakatothrix Wille.* Preslia 34: 277-292.

Hindák, F., Komárek, J., Marvan, P., and Ruzicka, J. 1973. *Kl'úc_Na Urcovanie-Výtrusných Rastlín*. I. diel, Raisy. Bratislava.

Hindák, F. 1980. *Studies on the Chlorococcal Algae (Chlorophyceae).* II. Biologicke Prace.

Hindák, F. 1984. *Studies on the Chlorococcal Algae (Chlorophyceae).* III. Biologicke Prace.

Hindák, F. 1988. *Studies on the Chlorococcal Algae (Chlorophyceae).* IV. Biologicke Prace.

Hindák, F. 1990. *Studies on the Chlorococcal Algae (Chlorophyceae).* V. VEDA, Bratislava. 225pp.

Hindak, F. 2001. *Fotograficky atlas mikrospopickych sinic (Atlas of Freshwater Cyanophytes). In Slovak, with English introduction, Latin species index and Latin nomenclature*. VEDA, Publishing House of the Slovak Academy of Sciences. Bratislava, Czech Republic. 347 color photographs, 128pp.

Hofmann, G., Werum, M. and Lange-Bertalot, H. 2013. *Diatomeen im Süßwasser—Benthos von Mitteleuropa*. Bestimmungsflora Kieselalgen für die ökologische Praxis. Über 700 der häufigsten Arten und ihre Ökologie. pp. [1]-908, 133pp. Königstein: Koeltz Scientific Books.

Holmgren, S. Ramberg, L. and Ånell, C. 1971. *Fytoplankton*. Limnologiska Institutionen, Uppsala.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Horner, R.A. 2002. *A Taxonomic Guide To Some Common Marine Phytoplankton*. Biopress Limited. Bristol, England. 195pp.

Hotzel, G. and Croome, R. 1999, *A Phytoplankton Methods Manual for Australian Freshwaters*, Land and Water Resources Research and Development Corp. 58pp.

Houk, V., et al. 2010. *Atlas of freshwater centric diatoms III. Cyclotella, Tertiarius, Discostella.* Fottea Supplement 498pp.

Houk, V., Klee R. and Tanaka, H. 2014. *Atlas of freshwater centric diatoms with a brief key and descriptions Part IV. Stephanodiscaceae B Stephanodiscus, Cyclostephanos, Pliocaenicus, Hemistephanos, Stephanocostis, Mesodictyon & Spicaticribra.* Fottea Supplement 530pp.

Huber-Pestalozzi, G. 1938 *Das Phytoplankton des Süßwassers, Systematik und Biologie*, In: Die Binnengewässer. Vol.16 (1), 342pp. Stuttgart, Schweizerbart'sche.

Huber-Pestalozzi, G. 1941. *Das Phytoplankton des Süßwassers Chrysophyceen, Farblose Flagellaten Heterokonten*. In: Die Binnengewässer, Band XVI, Teil 2, (i). E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Huber-Pestalozzi, G. 1942. *Das Phytoplankton des* Süßwassers Diatomeen. In: Die Binnengewässer, Band XVI, Teil 2, (ii). E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Huber-Pestalozzi, G. 1955. *Das Phytoplankton des* Süßwassers Euglenophyceen. In: Die Binnengewässer, Band XVI, Teil 4, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Huber-Pestalozzi, G. 1961. *Das Phytoplankton des Süßwassers Chlorophyceae, Ordnung: Volvocales.* In: Die Binnengewässer, Band XVI, Teil 5, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Huber-Pestalozzi, G. 1968. *Das phytoplankton des Süsswassers. Cryptophyceae, Chloromonadophyceae, Dinophyceae*. In: Die Binnengewässer. (Thienemann, A. Eds) Vol.16(3), 322pp. Stuttgart: Schweizerbart'sche. 2nd Edition.

Huber-Pestalozzi, G. 1972. *Das Phytoplankton des Süßwassers Chlorophyceae, Ordnung: Tetrasporales.* In Die Binnengewässer, Band XVI, Teil 6, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Hustedt, F. 1976. *Die Süsswasser-Flora Mitteleuropas. Heft 10: Bacillariophyta (Diatomeae).* Otto Koeltz Science Publishers.

Javornicky, P. and Popovsky, J. 1971. *Pyrrhophyta Common in Czechoslovakia*. Hydrobiolocial Laboratory of the Czechoslovak Academy.

Johansen, J.R. and Rushforth, S.R. 1985. *A contribution to the taxonomy of Chaetoceros muelleri Lemmermann (Bacillariophyceae) and related taxa.* Phycologia, Volume 24: 437-447.

John, D.M., Whitton, B.A. and Brook, A.J. 2002. *The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae.* Cambridge University Press. New York, NY 701pp.

John, D.M., Whitton, B.A. and Brook, A.J. 2011. *The Freshwater Algal Flora of the British Isles.* University of Cambridge Press, Cambridge, UK. 878pp.

John, J. 1981. *Three New Taxa of Diatoms From Western Australia.* Cryptogamie, Algologie, II 2: 131-139.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Joosten, T.A.M. 2006. *Flora of the blue-green algae of the Netherlands I The non-filamentous species of inland waters*. KNNV Publishing, Utrecht, The Netherlands.

Kesling, R. V. and Chilman, R. B. 2013. *Strata and Megafossils of the Middle Devonian Silica Formation*. The Friends, University of Michigan, Museum of Paleontology.

Klaveness, D. 1985. *Classical and modern criteria for determining species of Cryptophyceae.* Bulletin of Plankton Society of Japan 32:111-128.

Komárek, J. and Anagnostidis, K. 1986. *Modern approach to the classification system of Cyanophytes. 2 - Chroococcales*. Algological Studies 43:157-226, Archiv Fur Hydrobiologie, Supplementband 73, Stuttgart.

Komárek, J. and Anagnostidis, K. 1989. *Modern approach to the classification system of Cyanophytes. 4 - Nostocales*. Algological Studies 56:247-345, Archiv Fur Hydrobiologie, Supplementband 82, Stuttgart.

Komárek, J., and Anagnostidis, K. 2001. *Cyanoprokaryota I. Teil. Chroococcales.* In: H. Ettl, G. Gartner, H. Heynig & D. Mollenhauer (eds.), Susswasserflora von Mitteleuropa 19(1), G. Fischer, Jena. 548pp.

Komárek, J., and Anagnostidis, K. 2005. *Cyanoprokaryota II. Teil. Oscillatoriales*. In: B. Büdel, G. Gärtner, L. Krienitz & M. Schagerl (eds.), Susswasserflora von Mitteleuropa 19(2), Elsevier, Heidelberg. 759pp.

Komarek, J. 2013. *Cyanoprokaryota. III. Teil. Heterocytous Genera*. In: B. Büdel, G. Gärtner, L. Krienitz & M. Schagerl (eds.), Süßwasserflora von Mitteleuropa 19(3) Springer, Heidelberg. 1131pp.

Komarek, J. and Kling, H. 1991. *Variation in six planktonic cyanophyte genera in Lake Victoria (East Africa)*. Algological Studies 61:21-45.

Komárek, J. and Jankovskà, V. 2001. *Review of the Green Algal Genus Pediastrum; Implication for Pollenanalytical Research*. Bibliotheca Phycologica, Band 108, Edited by J. Cramer, Gebrüder Borntraeger Verlag Berlin/Stuttgart 127pp..

Krammer, K. 1981. *Observations on the Alveoli and Areolae of some Naviculaceae*. Ex: Beiheft 73 zur Nova Hedwigia,. Hindenburgstr 26a, D-4005 Meerbusch I.

Krammer, K. 1981. *Zur Deutung einiger Schalenstrukturen bei pennaten Diatomeen*. 4005 Meerbusch 1, Hindenburgstr. 26a, Nova Hedwigia, Band XXXV, Braunschweig.

Krammer, K. 1982. *Observations on the raphe slit of some Bacillariophyceae and ideas on its function*. Archiv für Hydrobiologie Suppliment 63.2 (Algological Studies 31): 177-188.

Krammer, K. 1982. *Micromorphology of Diatom Valves. Valve Morphology in the Genus Cymbella* C.A. Agardh, Plates 1024-1148.

Krammer, K. 1992. *Pinnularia: Eine Monographie der Europäischen Taxa*. Bibliotheca Diatomologica,. Band 26, J. Cramer, Stuttgart.

Krammer, K. 1997. *Die cymbelloiden Diatomeen. Teil 1. Allgemeines und Encyonema Part*. Bibliotheca Diatomologica, Edited by H. Lange-Bertalot and P. Kociolek., J. Cramer. Stuttgart 382pp.

Krammer, K. 1997. *Die cymbelloiden Diatomeen. Teil 2. Encyonema Part., Encyonopsis and Cymbellopsis.* Bibliotheca Diatomologica, Edited by H. Lange-Bertalot and P. Kociolek. J. Cramer, Stuttgart 486pp.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Krammer, K. 2000. *The genus Pinnularia. Diatoms of Europe, Volume 1*. Edited by H. Lange-Bertalot, A.R.G. Gantner Verlag K.G. FL 703pp.

Krammer, K. 2001. *Navicula sensu stricto 10 Genera Separated from Navicula sensu lato Frustulia. Diatoms of Europe, Volume 2*. Edited by H. Lange-Bertalot, A.R.G. Gantner Verlag K.G. FL 526pp.

Krammer, K. 2002. *Cymbella. Diatoms of Europe, Volume 3*. Edited by H. Lange-Bertalot, A.R.G. Gantner Verlag K.G. FL 584pp.

Krammer, K. 2003. *Cymbopleura, Delicata, Navicymbula, Gomphocymbellopsis, Afrocymbella. Diatoms of Europe, Volume 4*. Edited by H. Lange-Bertalot, A.R.G. Gantner Verlag K.G. FL 530pp.

Krammer, K. and Lange-Bertalot, H. 1986. *Bacillariophyceae. Teil 1. Naviculaceae.* Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertalot, H. 1988. *Bacillariophyceae. Teil 2. Bacillariaceae, Epithemiaceae, Surirellaceae.* Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertalot, H. 1991. *Bacillariophyceae. Teil 3. Centrales, Fragilariaceae, Eunotiaceae*. Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertalot, H. 1991. *Bacillariophyceae. Teil 4. Achnanthaceae, Kritische Ergänzungen zu Navicula (Lineolatae) and Gomphonema*. Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Stuttgart.

Krammer, K and Lange-Bertalot, H. 1991. *Bacillariophyceae. Teil 5. English and French translation of the keys*. Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Heidelberg.

Krammer, K. and Lange-Bertalot, H. 2000. *Bacillariophyceae. Part 5. English and French Translation of the Keys.* Süßwasserflora von Mitteleuropa, Band 2/5, Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertalot, H. 2001. *Bacillariophyceae. Teil 4. Achnanthaceae, Kritische Ergänzungen zu Navicula (Lineolatae) and Gomphonema [new edition].* Süßwasserflora von Mitteleuropa, Band 2, Gustav Fischer Verlag, Stuttgart.

Kristiansen, J. and Preisig, H.R. 2001. Encyclopedia of *Chrysophyte Genera.* Bibliotheca Phycologica, Band 110, J. Cramer. Stuttgart.

Kristiansen, J. and Preisig, H.R. 2007 *Chrysophyte and Haptophyte Algae. 2. Teil/Part 2: Synurophyceae, Freshwater Flora of Central Europe*. SuBwasserflora von Mitteleuropa, Spektrum Akademischer Verlag.

Kumano, S. 2002. *Freshwater Red Algae of the World*. Biopress Limited. Bristol, England 375pp.

La Rivers, I. 1978. *Algae of the Western Great Basin*. Bioresources Center. Reno, NV 390pp.

Lange-Bertalot, H. 1993. *85 neue Taxa und über 100 weitere neu definierte Taxa ergänzend zur* Süßwasserflora von Mitteleuropa, Vol. 2/1–4, Bibliotheca Diatomologica, Band 27. J. Cramer in der Gebrüder Borntraeger Verlagsbuchhandlung, Berlin, Stuttgart.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Lange-Bertalot, H. 2001. *Navicula sensu stricto 10 Genera Separated from Navicula sensu lato Frustulia.* Diatoms of Europe: Volume 2. A.R.G. Gantner Verlag K.G. FL 526pp.

Lange-Bertalot, H. and Le Cohu, R. 1985. *Raphe like vestiges in the pennate diatom suborder Araphidineae?* Annls Limnology 21 (3): 213-220.

Lange-Bertalot, H. and Ulrich. S. 2014. *Contributions to the taxonomy of needle-shaped Fragilaria and Ulnaria species.* Lauterbornia 78:1-73.

Ling, H.U. and Tyler, P.A. 2000. *Australian Freshwater Algae (exclusive of diatoms).* Bibliotheca Phycologica, Band 105 J. Cramer. Stuttgart. 643pp.

McGregor, G.B. 2001. *A New Planktic Species of Myxobaktron (Cyanoprokaryota, Chroococcales) from Tropical and Sub-tropical Freshwater Reservoirs in Queensland, Australia*, Algological Studies 103, Archiv für Hydrobiologie Supplement, Volume 140, E.Schweizerbart'sche Verlagsbuchhandlung, Stuttgart 162pp.

McGregor, G.B. 2007. *Freshwater Cyanoprokaryota of North-Eastern Australia I: Oscillatoriales*, Flora of Australia Supplementary Series no. 24, ABRS, Austrailia123pp.

Morales, E.A., Trainor, F.R. and Schlichting, C.D. 2002. *Evolutionary and ecological implications of plastic responses of algae*. Constancea 83:2002 (25 pp) Available on-line at http://ucjeps.berkeley.edu/constancea/83.

Patrick, R. and Reimer, C.W. 1967. *The Diatoms of the United States, Exclusive of Alaska and Hawaii.* Volume 1. Monograph of the Academy of Natural Sciences of Philadelphia, Number 13.

Patrick, R. and Reimer, C.W. 1975. *The Diatoms of the United States, Exclusive of Alaska and Hawaii*. Volume 2, Part 1. Monograph of the Academy of Natural Sciences of Philadelphia, Number 13. NOTE: There is no Volume 2, Part 2, the work is incomplete.

Patterson, D.J. 1996. *Free-living Freshwater Protozoa: A Colour Guide.* John Wiley & Sons, New York, NY.

Pennak, Robert W. 1989. *Fresh-Water Invertebrates of the United States Protozoa to Mollusca* (Third Edition). John Wiley & Sons, Inc., New York, NY 628pp.

Poulin, M. (Editor) 2004. *Proceedings of the Seventeenth International Diatom Symposium.* Ottawa, Canada, 25th -31st August 2003, IDS2002., Biopress Limited, Bristol, UK 480pp.

Prescott, G.W. 1978. *How to Know the Freshwater Algae.* Third Edition, Wm. C. Brown, Dubuque, IA.

Prescott, G.W. 1982. *Algae of the Western Great Lakes Area*. Second Edition. Otto Koeltz Science Publishers, Koenigstein.

Prescott, G.W., Croasdale, H.T. and Vinyard, W.C. 1975. *A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae,* Section 1. University of Nebraska Press, Lincoln.

Prescott, G.W., Croasdale, H.T. and Vinyard, W.C. 1977. *A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae*, Section 2. University of Nebraska Press, Lincoln.

Prescott, G.W., Croasdale, H.T. Vinyard, W.C., and Bicudo, C.E.M. 1981. *A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae,* Section 3. University of Nebraska Press, Lincoln.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Prescott, G.W., Bicudo, C.E.M. and Vinyard, W.C. 1982. *A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae*, Section 4. University of Nebraska Press, Lincoln.

Reavie, E.D. and Smol, J.P. 1998. *Freshwater diatoms from the St. Lawrence River*. Bibliotheca Diatomologia, Band 41, J. Cramer. Stuttgart.

Reavie, E. D. and Kireta A.R. 2015. *Centric, Araphid and Eunotioid Diatoms of the Coastal Laurentian Great Lakes. Sampling, Taxonomic Descriptions and Environmental Characteristics.* Bibliotheca Diatomologica, 62, 49 plates, 184pp.

Rosen, B.H., and St. Amand, A., 2015. *Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities*. U.S. Geological Survey Open-File Report 2015–1164, 44p.

Round, F.E., Crawford, R.M. and Mann, D.G. 1990. *The Diatoms*. Cambridge University Press. New York, NY.

Ruck, E.C. and Kociolek, J.P. 2004. *Preliminary Phylogeny of the Family Surirellaceae (Bacillariophyta)*. Gebruder Borntraeger, Stuttgart, Germany.

Sandhall, A. and Berggren, H. 1985. *Planktonkunde*. Kosmos, Stuttgart.

Sandgren, C.D., Smol, J.P. and Kristiansen, J. 1995. *Chrysophyte Algae Ecology, Phylogeny and Development*. Cambridge University Press. Great Britain. 399pp.

Schmidt, A. 1921. *Atlas Der Diatomaceen-Kunde*. Band II-IV, Serie IV-X, Tafel 145-420, Formenverzeichnis zu Otto Koeltz Antiquariat Koenigstein/Taunus.

Schoeman, F.R. and Archibald, R.E.M. 1986. *Observations on Amphora species (Bacillariophyceae)* in the British Museum (Natural History). I Some species from the subgenus Oxyamphora Cleve, Nova Hadwigia 43: 113-127.

Schoeman, F.R. and Ashton, P.J. 1982. *The Diatom Flora of the Pretoria Salt Pan, Transvaal, Republic of South Africa*. Bacillaria, Volume 5.

Serieyssol, K. and Sullivan, M.J. (Editors) 2002. Diatom Research Volume 17 Number 2. Biopress Limited. Bristol, England. 475pp.

Serieyssol, K.K. and Johansen, J.R. (Editors) 2007. Diatom Research Volume 22 Number 1. Biopress Limited. Bristol, England. 245pp.

Sims, P.A. 1996. *An Atlas of British Diatoms*. Biopress Ltd, Dorchester, UK.

Siver, P.A. 1991. *The Biology of Mallomonas: Morphology, Taxonomy and Ecology*. Kluwer Academic Publishers 230pp.

Siver, P.A., Hamilton, P.B., Stachura-Suchoples, K. and Kociolek, J. P. 2005. *Diatoms of North America. The Freshwater Flora of Cape Cod, Massachusetts, USA*. Iconographia Diatomologica, Volume 14, A.R.G. Gantner Verlag Kommanditgesellschaft 463 pp.

Skuja, H. 1956. *Taxonomische und Biologische Studien über das Phytoplankton Schwedischer Binnengewässer*. Nova Acta R. Soc. Scient., Ser IV, Vol. 16. No. 3, Almqvist and Wiksells Boktryckeri Ab, Uppsala.

Skulberg, O.M. and Cronberg, G. 1994. *Cyanobacteria : morphology, taxonomy, ecology, toxicology*. Proceedings of the 12th symposium of the International Association for

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

Cyanophyte Research (IAC), Sjoearp (Sweden). Archiv Für Hydrobiologie. Supplementband 105 Algological Studies, E. Schweizerbart, Stuttgart. 367pp.

Starmach, K. 1980. *Chrysophyta 1. Chrysophyceae --Zlotowiciowce.* Flora Slodkowodna Polski, Tom. 5, Warszawa, Krakow, PWN 775pp.

Taft, C.E. and Taft, C.W. 1990. *The Algae of Western Lake Erie.* College of Biological Sciences, Ohio State University, Columbus.

Tanaka, H. 2007. *Taxonomic Studies of the Genera Cyclotella (Kutzing) Brebisson, Discostella Houk et Klee and Puncticulata Hakansson in the Family Sephanodiscaceae Glezer et Makarova (Bacillariophyto) in Japan.* Bibl. Diatomologica 53, Gebruder Borntraeger, Berlin and Stuttgart 204pp.

Thorp, J.H. and Covich, A.P. 2001. *Ecology and Classification of North American Freshwater Invertebrates* (Second Edition). Academic Press, San Diego, CA 1056pp.

Tiffany, L.H. 1934. *The Plankton Algae of the West End of Lake Erie*. Ohio State University Press, Columbus.

Tilden, J. 1910. *The Myxophyceae of North America and Adjacent Regions* (Volume I of Minnesota Algae). Bibliotheca Phycologica., Band 4, Wheldon & Wesley, Ltd., Stechert-Hafner Service Agency, Inc., NY.

Tomas, C. R. (Editor) 1996. *Identifying Marine Diatoms and Dinoflagllates.* Academic Press, San Diego, CA 598pp.

Tomas, C. R. (Editor) 1993. *Marine Phytoplankton A Guide to Naked Flagellates and Coccolithophorids.* Academic Press, San Diego, CA 263pp.

Trainor, F.R. 1998. *Scenedesmus* Nova Hedwigia, Beiheft 117, Gebrüder Borntraeger Berlin & Stuttgart 367pp.

VanDenHoek, C. 1963, reprint 1976, *Revision of the European Species of Cladophora.* Otto Koeltz Science Publishers, Koenigstein 248 pp. 55 plates.

VanLandingham, S.L. 1982. *Guide to the Identification, Environmental Reuirements and Pollution Tolerance of Blue-Green Algae (Cyanophyta)*. Environmental Protection Agency, Cincinnati, OH 341pp.

Vinyard, W. 1979. *Diatoms of North America*. Mad River Press.

Wehr, J.D. and Sheath, R.G. 2003. *Freshwater Algae of North America*. Academic Press, Boston, MA 918pp.

Wehr, J.D., Sheath, R.G., and Kociolek J.P., 2015. *Freshwater Algae of North America.* Academic Press, New York, NY 1050pp.

West, W. and West, G.S. 1904. *A Monograph of the British Desmidiaceae*. Volume I, Adlard and Son, London.

West, W. and West, G.S. 1905. *A Monograph of the British Desmidiaceae*. Volume II, Adlard and Son, London.

West, W. and West, G.S. 1908. *A Monograph of the British Desmidiaceae*. Volume III, Adlard and Son, London.

SUPPLEMENT #2: ALGAL TAXONOMY

ALGAL KEYS AND TAXONOMIC REFERENCES

West, W. and West, G.S. 1912. *A Monograph of the British Desmidiaceae*. Volume IV, Adlard and Son, London.

Whitford, L.A. and Schumacher, G.J. 1984. *A Manual of Fresh-Water Algae*. Sparks Press, Raleigh, NC.

Wołowski, K. and Hindák, F. 2005. *Atlas of Euglenophytes*. VEDA, Publishing House of the Slovak Academy of Sciences, Bratislava, Czech Republic 136pp.

SUPPLEMENT #2: ALGAL TAXONOMY

SELECTED SOURCES FOR OBTAINING ALGAL KEYS

Koeltz Scientific Books (Europe)
P.O.B. 1360
D-6240 Koenigstein / West Germany

Balogh Scientific Books (formerly Koeltz USA)
1911 North Duncan Raod
Champaign, Illinois 61821
217-355-9331 or 217-355-9413

Lubrecht & Cramer, Ltd. (USA)
R.D. 1, Box 244
(Route 42 & Forestburgh Road)
Forestburgh, N.Y. 12777
914-794-8539

It is often possible to find important works in phycology at larger college/university libraries, and if they do not have what you need, they may be able to get it through interlibrary loan.

It is also often possible to get a university bookstore to conduct a search for a specific book of interest, especially if requested by a faculty member.

Also, many local libraries are able to locate and borrow taxonomic books through an interlibrary loan system.

SUPPLEMENT #2: ALGAL TAXONOMY

COMMON ALGAL TERMS

Acicular Needlelike in shape.

Acidophilic Tolerating or thriving in acid environments.

Acuminate Having pointed ends, tapered to a point.

Akinete Cyanophyte resting cyst.

Algae Thalloid plants, usually photosynthetically pigmented.

Alveola Shallow, minute, pit or cavity, a hollow space in the cell wall.

Apical Pertaining to the tip or end of a structure.

Apical axis The axis or rotation between two apices of a cell

Apiculate Having distinct apices, or end points, as with pointed tips

Arbuscular Growing in the form of a tree or bush.

Arcuate Strongly curved, crescent-shaped.

Attenuate To taper to a smaller width, narrowing gradually.

Axial Pertaining to an axis, an elongate filament or zone from which lateral parts originate.

Benthic Of or on the bottom, living on a substrate.

Calyptra Thickened cell wall at the tip of a filament, appearing as a cap.

Capitate Enlarged and set off at the apex, forming a head.

Carinal dot A pore associated with the raphe of a diatom within a canal on the valve face

Central nodule Thickened central area of valve (cell wall) in diatoms, usually associated with a terminal pore for a raphe

Chromatophore Cell organelle containing photosynthetic pigments.

Cingulum Part of diatom frustule connecting valves, part of girdle.

Clathrate Having branches or linear divisions, a dendritic shape

Clavate Club shaped, having one end thicker than the other.

Coccoid Spherical or ball shaped.

Coenobium A colony with cells arranged in a definite shape.

Coenocytic Multinucleate.

Colony (As a simplistic generic term) Non-filamentous aggregation of cells; additional terminology necessary to describe relationship of cells.

Conjugation Process of coming together, combining into one piece.

Cordate Heart shaped.

Costa Thickenings which appear like ribs.

Cruciate Cross-shaped.

Cyst Thick walled cell usually formed in response to unfavorable conditions, intended to form new plant at later date.

Dendroid Irregularly branched, appearing like a root system.

Dichotomous Having two choices, as in a taxonomic key or with simple branching.

Dimorphus Having two shapes, forms or phases.

Dorsal Pertaining to the upper or top structure.

Dorsiventral Having distinguishable upper and lower surfaces or structures.

Epilimnion Upper water layer, lighted and interacting with atmosphere.

Epilithic Growing on rock.

Epipelic Growing on soft sediment.

Epiphytic Growing on plants (or other substrates).

Epipsammic Growing on sand.

Epizoic Growing on an animal.

Eukaryote Cell with membrane-bound organelles.

Eyespot A photosensitive organelle, usually red in color, used in navigation by motile cells.

Fascia A distinguishing band across a cell face, as with the valve of certain diatoms

Filament A string of joined cells.

Flagellum Hair-like projection used for motility.

Foliose Leafy or leaf-like in appearance.

SUPPLEMENT #2: ALGAL TAXONOMY

COMMON ALGAL TERMS

Frustule The siliceous cell wall of a diatom.

Fusiform Elongate shape, widest at the middle and tapering to the ends.

Gamete Reproductive cell.

Gas vesicle Cell organelle containing gas, gives cyanophytes buoyancy.

Gibbous Swollen or enlarged, often in a central area.

Girdle To go around, portion of diatom frustule between valves.

Heterocyst Nitrogen-fixing cyanophyte cell.

Heterokont Having flagella of inequal length.

Heterotrichous Having two orientations, as with prostrate and erect thallus parts.

Hormogonium Set of cyanophyte resting cells.

Hypolimnion Lower water layer, dark and separate from atmosphere.

Intercalary Interspersed among other cells or plant parts, not apical or basal.

Isokont Having flagella of equal length.

Keel A ridge or flange.

Littoral Nearshore, lake bottom and/or water column within epilimnion.

Lorica Separate outer sheath encasing a cell, external to cell wall, also called a "test".

Medial Pertaining to the central portion

Metalimnion Middle water layer, transitional zone between epilimnion and hypolimnion.

Micron Micrometer, one thousandth of a millimeter.

Motile Possessing the ability to move under its own power.

Multiseriate Having more than one row of cells within what appears to be a single filament.

Non-motile Unable to move on its own.

Ocellus An eyespot or pigmented area sensitive to light.

Ovate Oval, with each end of equal curve.

Ovoid Egg shaped, with one end more pointed than the other.

Oogonium Specialized cell which acts as or produces an egg.

Operculate Having a lid or cover.

Palmelloid An indefinite arrangement of cells in mucilage.

Papilla A nipple-like protuberance.

Parenchymatous A mat-like arrangement of similar sized cells.

Parietal Arranged along the margin or circumference, not central.

Penicillate Brush-like.

Pennate Elongate, typically having bilateral symmetry.

Pelagic In open water, away from shore and littoral zone.

Pellicle Periplast, outer cell membrane in absence of true cell wall.

Periphyton Plants growing on a substrate, not free-floating.

Pervalvar axis The axis of rotation along a line connecting the center of two valves of a diatom cell, perpendicular to both the apical and transverse axes

Pinnate Structured like a feather, with a central axis and lateral fine branches.

Phycology The study of algae.

Planktonic Free-floating in the water column, not attached to substrate.

Prokaryote Cell with no membrane-bound organelles (Cyanophytes/bacteria).

Pseudoraphe False raphe, clear area of diatom valve along long axis, formed by ornamentation but having no locomotive function.

Puncta Small holes or pits in the cell wall, often in rows.

Pyrenoid Cell organelle which produces starch as food storage particles.

Pyriform Pear shaped.

Raphe Canal in diatom valve through which cytoplasm flows, causing motion.

Reniform Kidney shaped.

Reticulate Arranged in a mesh-like pattern, forming a network.

Rostrate Having extended or produced ends; more than rounded but less than capitate

Saccate Sack-like, balloon-like cell or group of cells, bulbous.

Scalariform Ladder-like, as with the conjugation of filaments in the Zygnematales.

SUPPLEMENT #2: ALGAL TAXONOMY

COMMON ALGAL TERMS

Serrate Toothed, having a jagged margin.
Sessile Non-motile, growing attached to some substrate.
Setae Hairs or bristles of a spine-like quality, projecting from a cell surface
Siphonaceous Having many nuclei in what appears to be one cell, often saccate or tubular.
Striated Marked with parallel lines made of discrete points.
Sulcus A dividing ring, as with the distinct central girdle bands of certain diatoms
Taxon Any given level of heirarchical identification, such as division, class, order, family, genus or species.
Thallus Plant body without differentiation into roots, stem and leaves.
Theca Armored cell wall, usually thickened by silica, cellulose or calcium.
Transverse axis The axis of rotation perpendicular to the apical axis across the face of a cell (usually the valve of a diatom)
Trichocyst Cell organelle which discharges cytoplasmic threads on stimulation, usually to capture external particles.
Trichome A thin hair, also a cyanophyte filament without sheath.
Truncate Cut off abruptly without graceful curves or a point.
Ubiquitous Widespread, commonly encountered.
Uniaxial (or Uniseriate) Having one row of cells comprising a filament.
Vacuole A clear space inside a cell, seemingly empty but likely to contain gas or a food storage product.
Valve Two end pieces of diatom frustule, usually highly ornamented.
Whorl Inserted in a ring around some base, as with multiple branches emanating at the same level from points around a stem.

SUPPLEMENT #2: ALGAL TAXONOMY

DERIVATION OF ALGAL NAMES

Very few algae have common names. Consequently, everyone must learn to communicate algal information using the proper scientific names, which are in Latin. Pronunciation can vary considerably among taxonomists, so don't feel embarrassed at not being sure how to say an algal name. Written names should be consistent, but may seem very cryptic if one is unfamiliar with Latin. Here are a few tips on understanding common Latin constructs in algal names.

Many algal species are named for some prominent feature of the species. Look for Latin roots of descriptive terms (see Common Algal Terms section). Examples include *Nitzschia acicularis* (acicular meaning needle-like; this species is very thin), *Scenedesmus acuminatus* (acuminate refers to pointed ends, which the cells of this species have), and *Oscillatoria limnetica* (limnetic indicating existence in open water, which is where this species is found). The ending on a specific epithet (species name) should match the ending on the genus name in most cases (e.g., *Dictyosphaerium pulchellum, Rhopalodia gibba*), but there are lots of exceptions.

Many algal species are named for famous phycologists. Specific epithets in these cases typically end in a single or more often double "i" (e.g., *Oscillatoria agardhii*, named after Agardh, or *Phacus lemmermannii*, named after Lemmermann, or *Draparnaldia judayi*, named after Juday). There are plenty of species names derived from last names of people which do not end in "i", but if you see "i" at the end, you can generally count on the preceding characters to represent someone's name and not a descriptive feature.

Many algal species are named after places in which they were found. Specific epithets in these cases typically end in "ensis" or "ense" (e.g., *Scenedesmus brasiliensis* or *Anabaena wisconsinense*). These tend to be more obvious than people's names, but if you see "ensis" or "ense" on the end of the specific epithet, the preceding characters refer to a place. Other than names and places, most elements of algal names come from Latin or Greek roots for descriptive terms. A working knowledge of these roots can be extremely helpful in deciphering what the name means and how it pertains to the alga to which it has been assigned.

SUPPLEMENT #2: ALGAL TAXONOMY

NOTES ON ALGAE IDENTIFICATION

Under ideal conditions, specimens of a given species being identified under magnification would be perfectly identical, be posed in all possible viewing positions, have all cell organelles easily visible, retain natural coloration, include reproducing stages, and move only as needed. In practice, almost none of these conditions occurs when viewing natural assemblages, so the taxonomist must make the best of an imperfect situation.

To meet this challenge, here are some tips on algae identification:

1. Keep accurate and informative notes on the collection site and methodology. Such information may aid some identification and will facilitate a more informed interpretation of data.

2. Work with live and preserved material when possible, and know the limitations of the preservative. It is seldom practical to perform counts on live samples, and identifications from live material, although helpful, will not always be transferrable to preserved specimens. If possible, take some live material back to the lab for comparison with preserved material, or even observe live material reaction to preservative when added in the lab. Know what the preservative does to specimen color, cell shape, colonial aggregations, and various organelles (esp. flagella). Use India ink to stain sheaths for easier observation under brightfield optics. Permanent mounts are ideal for long term storage, but keep wet material around for confirmation purposes. Temporary (hours to days) wet mounts can be made by ringing the coverslip with Vaseline. Leaving a small channel will allow replenishment of fluid or addition of stains. Make wet mounts as thin as possible for best resolution and highest viewing magnification, and observe different views by poking the coverslip with a thin but blunt object (either end of a pencil will often work well).

3. Observe filamentous or colonial traits.
  a. Are filaments branched?
  b. How are colonial cells connected?
  c. What are the dimensions of the colony or filament?
  d. How is the colony shaped, in two and three dimensions?
  e. Is the colony motile? If so, how does it move?
  f. Are all cells in the filament or colony alike?
  g. How many cells comprise the filament or colony?
Try to observe multiple examples of the same taxon. Variability in traits can be useful in identification, and no one colony or filament will necessarily provide all information necessary for a definite identification. Remember that preservation may cause some colonies to dissociate into individual cells or may distort overall growth form.

4. Observe individual cell traits.
  a. Cell shape and dimensions.
  b. Chromatophore color, number, shape and placement.
  c. Food storage particle type, size, number and placement.
  d. Other internal cell features, such as gas vesicles, vacuoles and eyespots.
  e. Ornamentation of cell wall, as with diatoms and desmids.
  f. Presence of flagella, number, relative lengths and placement.
  g. Presence of lorica, shape and color.
  h. Other external cell features, such as mucilage, spines or trichocysts.
  i. Specialized cell types, such as heterocysts, gametes, akinetes and other resting cysts.

SUPPLEMENT #2: ALGAL TAXONOMY

NOTES ON ALGAE IDENTIFICATION

As with colonies and filaments, observe multiple examples. No one cell will necessarily provide all needed information. It is harder to be convinced that a trait is absent than present, and viewing multiple examples will help confirm presence or absence of key traits. Remember that preservation may cause some features to change; some organelles may fall off, shrink, discolor or otherwise distort. Remember also that under natural conditions some features may vary in response to environmental factors; cell size, food storage, reproductive features, pigmentation and motility may be affected.

5. Make detailed composite drawings or a series of drawings for each species, showing different views. Alternatively, take photographs of specimens. Label key features and note dimensions of cells, colonies and filaments.

6. Know the limitations of the microscope. Are you using brightfield, phase contrast, or some other optical system? How does it distort color? What is the limit of resolution for each lens? Use of a Sedgewick-Rafter counting cell will limit magnification to 200X on most scopes; a Palmer-Maloney cell can be used at up to 400X. Glass slides with coverslips (wet or permanent mounts) or use of an inverted microscope can facilitate viewing at 1000X. Learn to use and maintain your microscope; optics and lighting should be adjusted to maximize visibility and resolution, and the image should be clear at all magnifications.

7. Use keys cautiously and record the steps taken when you are uncertain which choice to make. Unfortunately, keys work best when you already know the identity of the organism. However, the closer you get to the identity of the organism (e.g., within the correct order or family), the more useful most keys become. It is therefore most efficient to recognize the traits of common orders and families and to begin keying at that point. Simply leafing through pictures can be informative, but is very time consuming. A few hints for using keys:

a. Use multiple keys when possible; they're not all the same, and each may have something to offer.
b. More recent keys will be taxonomically more up to date and will often use photographs, but older keys will often have more rare taxa and better drawings; both are useful.
c. Do not assume that all taxa will be in any one key; few are 100% inclusive even for narrow groupings of algae, and none can cover the range of variants which can arise in response to environmental factors.
d. Use ecological or geographic information as well as visual data to make identifications.
e. Leave a paper trail; record steps along the key path as well as final outcome, including key author, date, volume, page number of the description, plate number of pictures, and any other relevant information.
f. Don't be afraid to change your mind as observation of more specimens yields additional information.
g. Watch out for errors; larger keys are very difficult to construct without error; use common sense. Keys are not sacred; correct your copy as needed, and make margin notes for your use wherever helpful.
h. Make use of experts when warranted; reasonable requests for help are rarely turned down, and those with more experience can often save you much time. Remember, however, that algal identification skills are acquired through many hours of observation; you need to spend time training yourself to observe, not just to recognize what an expert has pointed out. Make an effort at identifying the unknown, but when you reach your frustration limit, get help.
i. Make use of culture collections to broaden your exposure to algal taxa, but be wary of atypical growth forms which frequently occur in culture. Try keying a known culture to determine if it has retained the features necessary for its correct identification.

SUPPLEMENT #2: ALGAL TAXONOMY

NOTES ON ALGAE IDENTIFICATION

8. Once you have identified a specimen, make notes for yourself that could help the next time you encounter that taxon. In many cases you will be able to come up with features or memory-triggering devices which allow faster repeat identification. Reference pictures or preserved specimen slides can also be particularly useful.

9. Keep informed of algal taxonomy developments. Review technical journals such as the Journal of Phycology to keep current. Join an appropriate professional society, such as the Phycological Society of America, to maintain contacts. Subscribe to one or more of the Internet forums or home pages relating to algae. Examples include:

List Name	E-mail Address	Subscription Request Language
Lakes-L	majordomo@badger.state.wi.us	Subscribe Lakes-L *firstname lastname*
Algae-L	listserv@irlearn.ucd.ie	Subscribe Algae-L *firstname lastname*
Diatom-L	listserv@iubvm.ucs.indiana.edu	Subscribe Diatom-L *firstname lastname*
PSA	listserv@colostate.edu	Subscribe PSA *firstname lastname*
Ecolog-L	listserv@umdd.umd.edu	Subscribe Ecolog-L *firstname lastname*
Botany	majordomo@duracef.shout.net	Subscribe Botany *emailaddress*

Information in italics is not given literally, but as the appropriate personal data.

Favorite Algal World Wide Web Addresses

AlgaeBase
http://www.algaebase.org/

Diatom Home Page Biology Department, Indiana University
https://s10.lite.msu.edu/res/msu/botonl/b_online/library/diatoms/diatom.html

Catalogue Of Benthic Marine Algae Of The Indian Ocean
http://ucjeps.berkeley.edu/rlmoe/tioc/ioctoc.html

Phycological Society of America
http://www.psaalgae.org

EPA Office of Water, Clean Lakes Program
http://water.epa.gov/type/lakes/

Department of Biological Sciences of Bowling Green State University,
http://www.bgsu.edu/arts-and-sciences/biological-sciences/facilities-and-resources/algal-microscopy-laboratory/image-archive.html

Protist Image Data
http://www.bch.umontreal.ca/protists

Seaweed Site – National University of Ireland, Galway
http://www.seaweed.ie/

Iowa Lakeside Laboratory
http://www.continuetolearn.uiowa.edu/lakesidelab

SUPPLEMENT #2: ALGAL TAXONOMY

NOTES ON ALGAE IDENTIFICATION

Great Lakes Diatoms
http://www.umich.edu/~phytolab/GreatLakesDiatomHomePage/top.html

California Academy of Sciences
http://research.calacademy.org/izg/research/diatom

Cyanosite
http://www-cyanosite.bio.purdue.edu/index.html

River Diatoms, Common freshwater Diatoms of Britain and Ireland
http://craticula.ncl.ac.uk/EADiatomKey/html/

Smithsonian Institution's Algal Web Page
http://www.botany.si.edu/projects/algae

Diatoms of the Arid Southwest
http://aces.nmsu.edu/diatoms/index.html

Taxonomic Databases – Nomenclatural and taxonomic hierarchy, including authorship, synonyms, homonyms (incl. allowed ones) and common names when applicable.

Integrated Taxonomic Information Systems
www.itis.gov/
Taxonomicon
http://www.taxonomicon.net/
Algaebase
http://www.algaebase.org/

SUPPLEMENT #2: ALGAL TAXONOMY

A REVISED KEY FOR THE FIELD IDENTIFICATION OF SOME GENERA OF ALGAE

Adapted from a key by
Clarence E. Taft
Ohio State University

1. Living in or on animals 2
1. Not living in such close association with animals 5
   2. On shells of snapping turtles; filamentous, coarse, tufted .... Basicladia
   2. Not on turtle shells 3
3. Forming a hard green coating on snail shells .... Gongrosira
3. Not on snail shells 4
   4. In old egg masses of the salamander Ambystoma; dark green .... Oophila
   4. Living within green Hydra or Planaria .... (Zoo)Chlorella
5. Aquatic, submerged or nearly so 14
5. Not aquatic, on soil, rocks, concrete or bark 6
   6. On soil, rocks or concrete 8
   6. On wood or bark 7
7. On shaded side of tree trunks, or on weathered building siding .... Protococcus
7. On rotting logs or pilings, pale green .... Hormidium or Stichococcus
   8. On rocks or concrete 9
   8. On soil 10
9. Algal mass orange to reddish, on seemingly dry rock faces .... Trentepohlia
9. Algal mass dark olive to black, slimy if wet, peeling off surface if dry .... Oscillatoria
   10. Algal mass clearly filamentous, possibly felt-like, often in greenhouses 11
   10 Algal mass not filamentous or felt-like, varied locations 13
11. Dark green, felt-like, coarsely branched .... Vaucheria
11. Yellow green, tawny or olive brown 12
   12. Yellow green, filmy .... Hormidium or Stichococcus
   12. Tawney or olive brown, velvet- or felt-like .... Scytonema
13. Algal mass jelly-like, spherical or in expansive sheets .... Nostoc
13. Algal mass globular, 1-2 mm diameter, shining with white flakes .... Botrydium
   14. In running water, along shorelines, or in spray zone, attached 15
   14. In standing or very slowly moving water, attached or free 33
15. In cold water, during late winter or early spring unless spring-fed habitat 16
15. In cool to warm water, during late spring, summer or autumn 26
   16. Algal mass filamentous 17
   16. Algal mass not filamentous 23
17. Algal mass a felt-like mat .... Vaucheria
17. Algal mass not a felt-like mat 18
   18. Plants not branched 19
   18. Plants densely branched, bushy 20
19. Plants short, slippery, bright green .... Ulothrix
19. Plants nodulose, cartilaginous, olive .... Lemanea
   20. Plants embedded in a jelly-like mass 21
   20. Plants not gelatinous, coarse, often in swift water .... Cladophora
21 Plants olive green to reddish purple .... Batrachospermum

SUPPLEMENT #2: ALGAL TAXONOMY

A REVISED KEY FOR THE FIELD IDENTIFICATION OF SOME GENERA OF ALGAE

21. Plants brilliant green 22

  22. Gelatinous mass soft, indefinite, lateral branches long and at varying angles to main stem .... Stigeoclonium

  22. Gelatinous mass firm, definite, lateral branches short and at right angles to main stem .... Draparnaldia

23. Plant mass brownish, gelatinous, amorphous, a coating on rocks .... Diatoms

23. Plant mass green, gelatinous but not amorphous 24

  24. Plant mass tubular, convoluted, like green intestines .... Enteromorpha

  24. Plant mass saccate, membranous, possibly tubular but not convoluted 25

25. Plant mass firm, easily handled intact .... Monostroma

25. Plant mass delicate, readily disintegrating when handled .... Tetraspora

  26. Filamentous, branched or unbranched 27

  26. Not filamentous 31

27. Filaments branched 28

27. Filaments unbranched 30

  28. Algal mass a felt-like mat .... Vaucheria

  28. Algal mass not felt-like, usually in turbulent water 29

29. Algal mass bushy, coarse, dark green .... Cladophora

29. Algal mass slimy, bright green .... Stigeoclonium

  30. Filaments up to 15 cm, nodulose, dark olive .... Lemanea

  30. Filaments up to 60 cm, densely intertwined, coarse, green .... Rhizoclonium

31. Plant mass bead-like, olive to black, on rocks .... Nostoc

31. Plant mass not bead-like, green, varied substrates 32

  32. Green, calcareous encrustation on rocks or sticks .... Chlorotylium

  32. Colonies green, gelatinous pads or sacs .... Tetraspora

33. In cold water during late winter or early spring 34

33. In cool to warm water, during late spring, summer or autumn 39

  34. In woodland pools with leaf litter bottoms 35

  34. In open ponds, along lake margins, or in backwater areas 36

35. Algal mass yellow green, filamentous, silky .... Tribonema

35. Each plant a motile sphere just visible to the naked eye .... Volvox

  36. Plants tree-like, often calcareous, attached to bottom .... Chara or Nitella

  36. Plants filamentous, no apparent branching 37

37. Attached to sticks or vegetation, rarely a floating, tangled mass, not very slimy, light green .... Oedogonium

37. Free floating, very slimy 38

  38. Brilliant green, extremely slippery, ends of filaments curling when removed from water .... Spirogyra

  38. Varied shades of green, only slighlty slippery, ends of filaments not curling when removed from water .... Mougeotia or Zygnema

39. In temporary bodies of water 40

39. In permanent or rarely drying bodies of water 43

  40. In bird baths, urns, limestone shoreline depressions, reddish scum on bottom or sides .... Haematococcus

  40. In puddles, cow tracks, ruts, manure-contaminated pools 41

SUPPLEMENT #2: ALGAL TAXONOMY

A REVISED KEY FOR THE FIELD IDENTIFICATION OF SOME GENERA OF ALGAE

41. Bluegreen, olive or black, slimy, membranous, often on mud .... Oscillatoria
41. Green or reddish, living in or on the water 42
    42. Forming a green or reddish scum on the surface of ponds .... Euglena
    42. Coloring the water green throughout its depth .... Chlamydomonas or other Volvocales
43. In aquaria, bottles or culture dishes in laboratories or greenhouses 44
43. In ponds, along lake margins, or in backwater areas 45
    44. Appearing as a green film on glass walls .... Chlorella
    44. Coloring the water green throughout its depth .... Scenedesmus or Ankistrodesmus
45. On wet soil at water margins 46
45. In an aquatic habitat, floating or submerged 47
    46. Globular, gelatinous colonies .... Nostoc
    46. Slimy, membranous mats, bluegreen, olive or black .... Oscillatoria
47. Submerged and attached 48
47. Free floating 51
    48. Plants tree-like, often calcareous, growing on bottom sediment .... Chara or Nitella
    48. Not tree-like, not growing on bottom sediment 49
49. Clearly filamentous, attached to sticks or vegetation .... Oedogonium
49. Not clearly filamentous 50
    50. Small hemispherical or branched gelatinous colonies, green .... Chaetophora
    50. Flat green disks, often attached to cattail or water lily leaves .... Coleochaete
51. Algal mass forming a net-lke structure .... Hydrodictyon
51. Algal mass not net-like 52
    52. Algal mass a tough, membranous, paper-film sheet, green to black .... Lyngbya
    52. Algal mass not membranous 53
53. Algal mass filamentous, green 57
53. Algal mass not filamentous 54
    54. Each plant a green, motile sphere just visible to the naked eye .... Volvox
    54. Algal particles bluegreen to lime green, dispersed or floating as a scum 55
55. Particles appearing as chopped grass or small green flakes in water .... Aphanizomenon
55. Particles of linear or irregular shape, no distinct flakes 56
    56. Particles sometimes visible as small filaments when held up to the light .... Anabaena or Aphanizomenon
    56. Particles amorphous blobs, coiled if filamentous .... Anabaena or Microcystis
57. Filaments coarse, branched, not slippery 58
57. Filaments silky, unbranched, very slippery 59
    58. Filaments with well defined, scattered, dark, swollen areas .... Pithophora
    58. Filaments uniformly colored .... Cladophora
59. Brilliant green, extremely slippery, ends of filaments curling when removed from water .... Spirogyra
59. Varied shades of green, only slighlty slippery, ends of filaments not curling when removed from water .... Mougeotia or Zygnema

SUPPLEMENT #2: ALGAL TAXONOMY

FIELD KEY TO SOME FRESHWATER ALGAE

Adapted from a key by
Hannah T. Croasdale
Dartmouth College

1. In still water, lakes, ponds or ditches 2
1. In flowing water 56
2. Not attached .... A
2. Attached 31
A. In filaments or jelly masses 3
A. Not filaments or jelly masses; scum or film, or evenly distributed, coloring water .... B
B. Brownish scum or film, often glistening .... Diatoms
B. Not brownish in color C
C. Bluegreen or whitish green in color .... Bluegreen algae, esp. Microcystis and Anabaena
C. Green, red or yellow green .... D
D. Bright grass green or red, or mixed green and red .... E
D. Yellow green or olive green .... F
E. Metallic green or red surface film .... Euglena
E. Not a surface film, bright green or possibly reddish .... Volvocales, esp. Chlamydomonas
F. Plant masses just visible to the naked eye as dark dots .... Botryococcus
F. Plants not discernible to the naked eye .... Chlorobotrys
3. Grass or pale green plants 15
3. Not green or another shade of green 4
4. Bluegreen 5
4. Not bluegreen 10
5. Jelly blobs or smears, tending to break when handled .... Anabaena or Cylindrospermum
5. Structurally otherwise 6
6. Tufted 7
6. Not tufted 8
7. Tufts soft, not hairy .... Tolypothrix or possibly Stigonema
7. Tufts coarse, hairy .... Scytonema crispum
8. Mass shattered completely when handled .... (green Stentor: chlorella in a protozoan)
8. Mass not shattered when handled 9
9. Thin but tough sheet .... Phormidium
9. Mass composed of fine hairs .... Oscillatoria or Lyngbya
10. Golden brown to dark brown 11
10. Olive green to black 14
11. Soft or gelatinous, not thready 12
11. Thready, often with trapped air bubbles 13
12. Frothy, not gelatinous .... (Iron bacteria)
12. Not frothy, at least somewhat gelatinous .... Diatoms
13. Breaking easily upon handling .... Fruiting Spirogyra, Zygnema or Mougeotia
13. Not breaking easily upon handling .... Non-fruiting Spirogyra, Zygnema or Mougeotia

SUPPLEMENT #2: ALGAL TAXONOMY

FIELD KEY TO SOME FRESHWATER ALGAE

14. Somewhat slippery .... Oscillatoria or Lyngbya
14. Clinging and web-like .... Mougeotia (purple form)
15. Grass green, bright or pale 16
15. Dirty yellow green, often spotted with brown 27
16. Jelly-like, breaking on handling 17
16. Structurally otherwise 18
17. Bright green, found mainly in early spring .... Tetraspora
17. Pale green, found mainly during mid-summer .... Schizochlamys or Chlorobotrys
18. Tubular structure .... Enteromorpha
18. Not tubular 19
19. Structure net-like .... Hydrodictyon
19. Not net-like 20
20. Much branched filaments in dense mats or tufts .... Cladophora
20. In mats of unbranched filaments 21
21. Not slippery 22
21. Slippery 24
22. Filaments coarse .... Oedogonium
22. Filaments fine and clinging, web-like 23
23. Difficult to gather .... Mougeotia (sterile)
23. Easy to gather .... Microspora
24. Filaments large enough to be distinct, curling from bottom when held up .... Spirogyra (sterile)
24. Filaments finer, scarcely distinct 25
25. Breaking when handled .... Filamentous desmids (except Hyalotheca)
25. Not breaking when handled 26
26. Very slippery, hard to hold .... Hyalotheca
26. Less slippery, easily held .... Zygnema (sterile)
27. Not slippery 28
27. Slippery 29
28. Soft, hard to gather .... Mougeotia (sterile)
28. Stringy, clinging and web-like .... Tribonema
29. Not breaking up in handling .... Spirogyra or Zygnema (sterile)
29. Breaking up in handling 30
30. Gritty .... Spirogyra (fruiting)
30. Fluffy .... Mougeotia or Zygnema (fruiting)
31. Film or blob or very gelatinous filament 32
31. Non-gelatinous filaments 42
32. Green, mainly found in spring 33
32. Not green 35
33. Stiff gelatinous balls or lumps .... Chaetophora
33. Softer, not in balls or lumps 34
34. No evidence of filaments in gelatinous matrix .... Tetraspora
34. Branched filament encased in gelatinous matrix .... Draparnaldia
35. Bluegreen 36
35. Not bluegreen 38
36. Thin sheet, stays more or less intact .... Phormidium
36. Otherwise 37

SUPPLEMENT #2: ALGAL TAXONOMY

FIELD KEY TO SOME FRESHWATER ALGAE

37.	Tufted filaments in jelly, usually in springy areas	Batrachospermum
37.	Blob or film, breaking up easily	Anabaena or Cylindrospermum
38.	Olive green to black	Oscillatoria or Lyngbya
38.	Yellowish or brown	39
39.	Indistinct slipperiness on rocks or weeds	Diatoms
39.	Floating blobs	40
40.	Pale greenish to yellow, soft irregular lumps of jelly	Schizochlamys or Chlorobotrys
40.	Rich yellow brown or reddish brown	41
41.	Even textured, glistening	Diatoms
41.	Flocculose, dull	Iron bacteria (not algae)
42	Green	43
42.	Not green	50
43.	In beds or isolated tufts on bottom of ponds, up to 18 inches tall with whorled branches	44
43.	Not in visible beds or tufts, smaller, no distinct stem or whorled branches	45
44.	Soft, flexible, no foul smell	Nitella
44.	Coarse, often brittle, foul smelling	Chara
45.	In obviously branched tufts	46
45.	Not in tufts of branched filaments	48
46.	Very pale, barely visible as tufts	Bulbochaete
46.	Coarse, darker, branches or tufts evident	47
47.	Deep green, soft, mostly observed in spring	Stigeoclonium
47.	Gray green, webby, more often observed in summer	Cladophora
48	Very coarse filaments, not slippery, in mats or on soil	Vaucheria
48.	Fine to moderately coarse filaments, slippery (especially larger filaments), evenly covering surface of plants or rocks	49
49.	Very slippery filaments	Spirogyra (sterile)
49.	Not very slippery filaments	Oedogonium
50.	On rocks	51
50.	On submerged plants	54
51.	Gelatinous balls	52
51.	Wooly, hairy or tufted forms	53
52.	Balls easily crushed, usually light in color	Nostoc
52.	Balls not easily crushed, darker in color	Rivularia
53.	Dark, velvet-like patches, usually wooly	Calothrix
53.	Erect tufts, usually hairy	Stigonema
54.	Very dark, short, hairy growths	Stigonema
54.	Soft, bluegreen or blue-gray growths	55
55.	In tufts	Tolypothrix
55.	Evenly distributed	Hapalosiphon
56.	Green	57
56.	Not green	62

SUPPLEMENT #2: ALGAL TAXONOMY

FIELD KEY TO SOME FRESHWATER ALGAE

57. Filamentous 58
57. Not filamentous, usually gelatinous blobs 61
    58. Filaments clearly branched 59
    58. Filaments not branched .... Ulothrix
59. Whitish or grayish green, tufted or stringy .... Cladophora
59. Rich grass green, mainly observed in spring 60
    60. Fragile, filaments spotty in gelatinous matrix .... Draparnaldia
    60. Not fragile, not gelatinous, soft, branched, tufted .... Stigeoclonium
61. In soft tubes or gelatinous sheets in slow water .... Tetraspora
61. Forming chains or series of jelly blobs .... Draparnaldia
    62. Bright bluegreen or olive green, gelatinous, up to 12 inches .... Batrachospermum
    62. Otherwise colored or structured 63
63. Pale green, olive green or black 64
63. Reddish brown or yellowish 68
    64. Dark, velvet-like fuzz .... Calothrix
    64. Jelly balls or film 65
65. Plant mass formed into balls 66
65. Plant mass a film, often in organically enriched water 67
    66. Tough jelly mass, slips aside when squeezed .... Rivularia
    66. Soft jelly mass, crushes when squeezed .... Nostoc
67. Hairy plant mass .... Oscillatoria or Lyngbya
67. Slimy film or sheet .... Phormidium
    68. Yellowish, fragile jelly filament, usually in cold moutain brooks .... Hydrurus
    68. Reddish brown, not gelatinous 69
69. Coarse, knotty, unbranched strands .... Lemanea
69. Red fuzz on rocks or wood in splash zone .... Trentepohlia

SUPPLEMENT #2: ALGAL TAXONOMY

THE WAGNER-WINDRATH KEY
To Commonly Encountered Detritus

Edited from the original 1975 key

Phylum: Detritophyta (or Amorphophycophyta)
Generally amorphous blobs and varied filaments. Often having no true cell walls or cells for that matter. May be coated with chitin, pectin or cellulose. No reproduction of any sort has been observed, yet these "organisms" are in great abundance and frequently interfere with microscopic analyses. No known economic importance has been ascribed to this group, which causes great confusion among novice taxonomists.

One Class: Detritophyceae
One Order: Detritocales
Two Families: Sweaterfilamentaceae - Filamentous forms
Confusococcaceae - Non-filamentous forms

1. Filamentous forms 2
1. Roundish or amorphous blobs 5
   2. Exhibiting apical-basal differentiation 3
   2. Not exhibiting such differentiation 4
3. Possessing distinct joints, bending at determinable angles....... Insectilegum fragmentalum
3. Segmented without bent joints, curving gracefully .... Antennia curvata
   4. Single filaments, epiphytic or epizooic, although often found without substrate, usually very smooth, sheathed and elongate .... Hairopsis
      A. Epiphytic origin.. H. plantoriginalis
      B. Epizooic origin .... H. animalis
   4. Filaments free, often in tangled masses, no sheaths, varying lengths and widths, but typically short and curly ......Sweaterfilamentus confusiformus
      (This taxon also applies to unidentifiable algal filaments)
      A. Colorless.. S.c. var. achromatus
      B. Reddish.. S.c. var. rosea
      C. Bluish .... S.c. var. cyania
      D. Greenish .... S.c. chlorium
      E. White .... S.c. albans
      F. Dark and opaque .... S.c. var. nigrescens
5. Distinguishable shapes, spheres or blobs 6
5. Completely indistinguishable.. Krappus
   A. Randomly dispersed.. K. krappus
   B. Organized into discernible but amorphous lumps or balls........................ K. lumpus
   6. Exterior smooth, particles typically round to ovate 7
   6. Exterior rough, often with blunt projections, varying shapes 8

SUPPLEMENT #2: ALGAL TAXONOMY

THE WAGNER-WINDRATH KEY
To Commonly Encountered Detritus

7\. Defining border of particle thick and dark, interior colorless,
particles spherical.. Aerobubblides croasdalii

7\. Particle borders thin, particles spherical to ovate, often greenish,
potentially algae but unidentifiable..Confusococcus obscurus

  8\. Particle border generally faceted and angular, sometimes
  with smoothed edges, interior clear .... Sandgrainium amorphosum

  8\. Particle lobed or with hairlike projections, usually opaque
  or at least not transparent .... Pollenia grainia

  8\. Anything else ....Particulosa heaferii
  (After an eminent detritologist but inept phycologist)

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

DETRITOPHYTA DRAWINGS

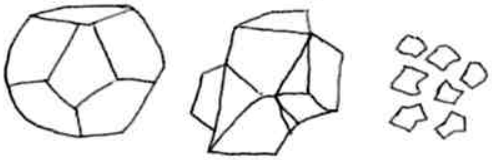
Sweaterfilamentus confusiformis

Antennia curvata

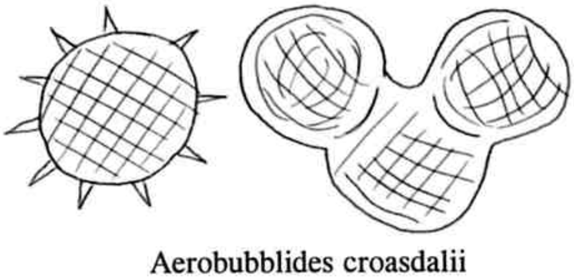
Hairopsis
[a.) filament and b.) section]

Insectilegum fragmentalis

Sandgrainium amorphosii



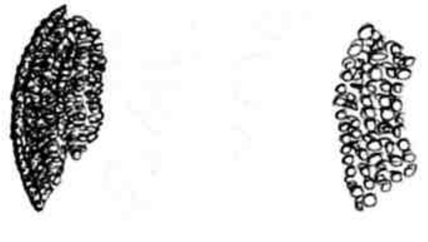
Pollenia grainiensis



Confusococcus obscurum

Aerobubblides croasdalii

Krappus krappus
[a.) at low power and b.) at high power]



Krappus lumpus

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Anderson, D.M., Cembella, A.D. and Hallegraeff, G.M. 1998. *Physiological Ecology of Harmful Algal Blooms.* Springer-Verlag Berlin Heidelberg, New York, NY 662 pages.

Bahls, L.L. 1973. *Diatom community response to primary wastewater effluent*. Journal of the Water Pollution Control Federation 45:134-144.

Barica, J. and Mur, L-R. (Editors) 1980. *Hypereutrophic Ecosystems.* Dr. W. Junk, Netherlands.

Bold, H.C. and Wynne, M.J. 1985. *Introduction to the Algae*. Second Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ 720 pp.

Butcher, R.W. 1947. *Studies in the ecology of rivers VII: The Algae of organically enriched waters*. Journal of Ecology 35:186-191

Canfield, D.E., Philips, E. and Duarte, C.M. 1989. *Factors influencing the abundance of blue-green algae in Florida lakes*. Canadian Journal of Fisheries and Aquatic Sciences 46:1232-1237.

Chow-Fraser, P., Trew, D., Findlay, D. and Stainton, M. 1994. *A test of hypotheses to explain the signoid relationship between total phosphorus and chlorophyll a concentrations in Canadian lakes*. Canadian Journal of Fisheries and Aquatic Sciences 51:2052-2065.

Cattaneo, A. 1987. *Periphyton in lakes of different trophy*. Canadian Journal of Fisheries and Aquatic Sciences 44:296-303.

Cattaneo, A. 1992. *The anthropogenically stressed periphyton of Lake Orta, Italy*. Hydrobiologia 234:111-121.

Chorus, I. and Bartram, J. 1999. *Toxic Cyanobacteria in Water*. E & FN Spon, New York. NY 446pp.

Colburn, E.A. 2004. *Vernal Pools Natural History and Conservation.* McDonald & Woodward Publishing Company, Blackburg, VA.

Cole, G.A. 1994. *Textbook of Limnology.* Fourth Edition. Waveland Press, Inc., Prospect Heights, IL 412pp.

Corbelas, M. and Rojo, C. 1994. *Factors influencing the share of planktic diatoms in lakes*. Algological Studies 74:73-104.

Cramer, J. 1996. *Dictionary of Plant Names in Latin, German, English and French*. Berlin Stuttgart 926pp.

Cushing, C.E. and Allan, J.D. 2001. *Streams: Their Ecology and Life*. Academic Press, Inc., San Diego, CA 366pp.

Duarte, C.M., Agusti, S. and Canfield, D.E. 1992. *Patterns in phytoplankton community structure in Florida lakes*. Limnology and Oceanography 37:155-161.

Edsall, T.A., Stoermer, E.F. and Kociolek, J.P. 1991. *Periphyton accumulation at remote reefs and shoals in Lake Superior.* Journal of Great Lakes Research 17:412-418.

Edsall, T, and Munawar, M. (Editors) 2005. *State of Lake Michigan: Ecology, Health and Management.* Goodword Books, New Delhi.

Eloranta, P. 1986. *Phytoplankton structure in different types of lakes in central Finland*. Holarctic Ecology 9:214-224.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Ennis, G.L. 1975. *Distribution and abundance of benthic algae along phosphate gradients in Kootenay Lake, British Columbia*. Verhandlungen des Internationalen Verein Limnologie 19:562-570.

Fairchild, G.W. and Sherman, J.W. 1992. *Linkage between epilithic algal growth and water column nutrients in softwater lakes*. Canadian Journal of Fisheries and Aquatic Sciences 49:1641-1649.

Fairchild, G.W. and Sherman, J.W. 1993. *Algal periphyton response to acidity and nutrients in softwater lakes: lake comparison vs. nutrient enrichment approaches*. Journal of the North American Benthological Society 12:157-167.

Goldman, C.R. and Horne, A.J. 1983. *Limnology*. McGraw Hill, Inc., New York, NY 464 pp.

Hansson, L-A. 1992. *Factors regulating periphytic algal biomass*. Limnology and Oceanography 37:322-328.

Harris, G.P. 1986. *Phytoplankton Ecology: Structure, Function and Fluctuation*. Chapman and Hall, New York, NY 384pp.

Hauer, F.R. and Lamberti, G.A., (Editors) 2006. *Methods in Stream Ecology*. Second Edition, Academic Press, Burlington, MA.

Hawes, I. and Smith, R. 1993. *Effect of localised nutrient enrichment on the shallow epilithic periphyton of oligotrophic Lake Taupo, New Zealand*. New Zealand Journal of Marine and Freshwater Research 27:365-372.

Hawes, I. and Smith, R. 1994. *Seasonal dynamics of epilithic periphyton in oligotrophic Lake Taupo, New Zealand*. New Zealand Journal of Marine and Freshwater Research 28:1-12.

Hecky, R.E. and Kilham, P. 1988. *Nutrient limitation of phytoplankton in freshwater and marine environments: a review of recent evidence on the effects of enrichment*. Limnology and Oceanography 33:796-822.

Holmgren, S. 1984. *Experimental lake fertilization in the Kuokkel area, Northern Sweden: Phytoplankton biomass and algal composition in natural and fertilized subarctic lakes*. Internationale Revue der Gesamten Hydrobiologie 69:781-817.

Huisman, J., Mattijs, C.P. and Visser, P. (Editors). 2005. *Harmful Cyanobacteria*. Springer, Norwell, MA 241pp.

Hulot, F.D. and Huisman, J. 2004. *Allelopathic interactions between phytoplankton species: The roles of heterotrophic bacteria and mixing intensity.* Limnology and Oceanography 49:1424-1434.

Hutchinson, G.E. 1967. *A Treatise on Limnology, Vol. II: Introduction to Lake Biology and the Limnoplankton.* J. Wiley & Sons, Inc., New York, NY.

Hyenstrand, P., Blomqvist P. and Pettersson, A. 1998. *Factors determining cyanobacterial success in aquatic systems – a literature review*. Archiv Fur Hydrobiologie, Special Issues Advanced Limnology 51:41-62.

Hynes, H.B.N. 1970. *The Ecology of Running Waters.* University of Toronto Press, Chapter IV, "Attached Algae," pp. 53-77.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Jensen, J.P., Jeppenson, E., Olrik, K. and Kristensen, P. 1994. *Impact of nutrients and physical factors on the shift from cyanobacterial to chlorophyte dominance in shallow Danish lakes*. Canadian Journal of Fisheries and Aquatic Sciences 51:1692-1699.

Kalff, J. 2002. *Limnology*. Prentice Hall, Saddle River, NJ 592pp.

Kalff, J. and Knoechel, R. 1978. *Phytoplankton and their dynamics in oligotrophic and eutrophic lakes*. Annual Review Ecological Systems 9:475-495.

Klausmeier, C., Litchman, E. and Levin, S. 2004. *Phytoplankton growth and stoichiometry under multiple nutrient limitation*. Limnology and Oceanography 49:1463-1470.

Kolkwitz, R. and Marrson, M. 1909. *Ecology of plant saprobia*. In: Keup, L.E. et al (Editors), 1967 Biology of Water Pollution. USDI, FWPCA, Cincinnati, OH.

LaZerte, B. and Watson, S. 1981. *The prediction of lacustrine phytoplankton diversity*. Canadian Journal of Fisheries and Aquatic Sciences 38:524-534.

Lee, R.E.1989. *Phycology*. 2nd Edition. Cambridge University Press,New York, NY 645pp.

Lehman, J.T., Abella, S., Litt, A. and Edmondson, W.T. 2004. *Fingerprints of biocomplexity: Taxon-specific growth of phytoplankton in relation to environmental factors*. Limnology and Oceanography 49:1446-1456.

Lehman, J.T. and Sandgren, C.D. 1985. *Species specific rates of growth and grazing loss among freshwater algae.* Limnology and Oceanography 30:34-46.

Lindstrom, E.A. 1994. *Periphyton investigations in Humex Lake Skjervatjern in 1992*. Environment International 20:321-328.

Litchman, E., Klausmeier, C. and Bossard, P. 2004. *Phytoplankton nutrient competition under dynamic light regimes*. Limnology and Oceanography 49:1457-1462.

Loeb, S.L. 1986. *Algal biofouling in oligotrophic Lake Tahoe: causal factors affecting production*. Pages 159-173 in: Evans, L.V. and Hoagland, K.D. (Editors) Algal Biofouling. Elsevier Publishers, Amsterdam.

Lowe, R.L. 1974. *Environmental Requirements and Pollution Tolerance of Freshwater Diatoms.* EPA-670/4-74-005 USEPA, Cincinnati, OH.

Marks, J.C. and Lowe, R.L. 1993. *Interactive effects of nutrient availability and light levels on the periphyton composition of a large oligotrophic lake*. Canadian Journal of Fisheries and Aquatic Sciences 50:1270-1278.

Mazumber, A., Taylor, W.D., McQueen, D.J. and Lean, D.R.S. 1989. *Effects of nutrients and grazers on periphyton phosphorus in lake enclosures*. Freshwater Biology 22:405-415.

McCauley, E., Watson, S. and Downing, J. 1989. *Sigmoid relationships between nutrients and chlorophyll among lakes*. Canadian Journal of Fisheries and Aquatic Sciences 46:1171-1175.

McQueen, D. and Lean, D.R.S. 1987. *Influence of water temperature and nitrogen to phosphorus ratios on the dominance of blue-green algae in Lake St. George*. Canadian Journal of Fisheries and Aquatic Sciences 44:598-604.

Moss, B. 1980. *Ecology of Freshwaters.* Blackwell Scientific Publishers, London, England 332pp.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Munawar, M., Edsall, T. and Munawar, I.F., 1999. *State of Lake Erie: Past, Present and Future*. Backhuys Publishers, Leiden, The Netherlands.

Munawar, M. and Munawar, I.F., 2000. *Phytoplankton Dynamics in the North American Great Lakes,* Volume 2, Backhuys Publishers, The Netherlands.

Oliver, R.L. 1994. *Floating and sinking in gas-vacuolate Cyanobacteria - a review*. Journal of Phycology 30:161-173.

Pearl, H. 1988. *Nuisance phytoplankton blooms in coastal, estuarine and inland waters*. Limnology and Oceanography 33:823-844.

Pearsall, W.H. 1932. *Phytoplankton in the English lakes II: The composition of the phytoplankton in relation to dissolved substances*. Journal of Ecology 20: 241-262.

Percival, S.L., et al., (Editors) 2004. *Microbiology of Waterborne Diseases*. Elsevier Academic Press.

Pires, L., Bontes, B., Van Donk E. and Ibelings, B. 2005. *Grazing on colonial and filamentous, toxic and non-toxic cyanobacteria by the zebra mussel Dreissenia polymorpha*. Journal of Plankton Research 27:331-339.

Reynolds, C.S. 1984. *The Ecology of Freshwater Phytoplankton*. Cambridge University Press, New York NY 384 pp.

Reynolds, C.S. 1987. *Cyanobacterial water blooms*. Advances in Botanical Research 13:67-143.

Reynolds, C.S. 1992. *Dynamics, selection and composition of phytoplankton in relation to vertical structure in lakes*. Archiv Fur Hydrobiologie 35:13-31.

Reynolds, C.S. and Bellinger, E.G. 1992. *Patterns of abundance and dominance of the phytoplankton of Rostherne Mere, England: Evidence from an 18-year dataset.* Aquatic Sciences 54:11-36.

Reynolds, C.S. 1998. W*hat factors influence the species composition of phytoplankton in lakes of different trophic status?* Hydrobiologie 369/370:11-26.

Riber, H.H. and Wetzel, R.G. 1987. *Boundary layer and internal diffusion effects on phosphorus fluxes in lake periphyton*. Limnology and Oceanography 32:1181-1194.

Round, R.E. 1981. *The Ecology of Algae*. Cambridge University Press, New York, NY 653pp.

Sandgren, C.D. 1988. *Growth and Reproductive Strategies of Freshwater Phytoplankton.* Cambridge University Press, New York, NY 442pp.

Sandgren, C.D., Smol, J.P. and Kristiansen, J. (Editors) 1995. *Chrysophyte Algae: Ecology, Phylogeny and Development.* Cambridge University Press, New York, NY 399pp.

Scheffer, M. 2004. *Ecology of Shallow Lakes*. Springer, Berlin 374pp.

Seip, K.L. and Reynolds, C.S. 1995. *Phytoplankton functional attributes along trophic gradient and season*. Limnology and Oceanography 40:589-597.

Shane, M.S. et al. 1971. *Water quality and plankton ecology - the Christina River, Delaware*. Environmental Pollution 2:81-95.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Shortreed, K.S., Costella, A.C. and Stockner, J.G. 1984. *Periphyton biomass and species composition in 21 British Columbia lakes: seasonal abundance and response to whole-lake nutrient additions*. Canadian Journal of Botany 62:1022-1031.

Smith, V.H. 1982. *The nitrogen and phosphorus dependence of algal biomass in lakes: an empirical and theoretical analysis*. Limnology and Oceanography 27:1101-1112.

Smith, V.H. 1986. *Light and nutrient effects on the relative biomass of blue-green algae in lake phytoplankton*. Canadian Journal of Fisheries and Aquatic Sciences 43:148-153.

Smol, J.P., Battarbee, R.W., Davis, R.B. and Meriläinen, J. (Editors). 1986. *Diatoms and Lake Acidity. Reconstructing pH from siliceous algal remains in lake sediments*. Dr. W. Junk Publishers, Dordrecht, The Netherlands 307pp.

Sommer, U. 1989. *Plankton Ecology: Succession in Plankton Communities.* Springer-Verlag, New York, NY 369pp.

Sterner, R.W. 1990. *Resource competition and the autecology of pennate diatoms*. International Association of Theoretical and Applied Limnology 24:518-524.

Stevenson, R.J., Bothwell, M.L. and Lowe R.L. (Editors) 1995. *Algal Ecology: Freshwater Benthic Ecosystems.* Academic Press, San Diego, CA 753 pp.

Stevenson, R.J., Pan, Y., Kociolek, J.P. and Kingston, J.C. (Editors) 2006. *Advances in Algal Biology: A Commemoration of the Work of Rex Lowe*. Springer, The Netherlands.

Stewart, A.J. and Wetzel, R.G. 1986. *Cryptophytes and other microflagellates as couplers in planktonic community dynamics*. Archiv fur Hydrobiologie 106:1-19.

Tilman, D. et al. 1986. *Green, blue-green and diatom algae: Taxonomic differences in competitive ability for phosphorus, silicon and nitrogen*. Archiv fur Hydrobiologie 106:473-485.

Trainor, F. R. 1998. *Biological Aspects of Scenedesmus (Chlorophyceae) – Phenotypic Plasticity.* Gebruder Borntraeger Verlag.

VanDenHoek, C., Mann D.G. and Jahns H.M. 1995. *Algae: An Introduction to Phycology.* Cambridge University Press, Cambridge NY 623pp.

VanLandingham, S.L. 1982. *Guide to the Identification, Environmental Requirements and Pollution Tolerance of Bluegreen Algae (Cyanophyta).* EPA/3-82-073, USEPA, Washington, DC.

Vymazal, J. 1995. *Algae and Element Cycling in Wetlands*. Lewis Publishers, Boca Raton, FL.

Warren, C.E. and Doudoroff, P. 1971. *Biology and Water Pollution Control.* W.B. Saunders Co., Phila., PA.

Watanabe, M.F. 1996. *Toxic Microcystis*. CRC Press, Inc. New York, NY 262pp.

Watson, S.B., McCauley, E. and Downing, J.A. 1997. *Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status*. Limnology and Oceanography 42:487-495.

Welch, E.B. and Jacoby, J.M., 2004. *Pollutant Effects in Freshwater Applied Limnology*. Third Edition, Spon Press, New York, NY.

Wetzel, R.G. 2001. *Limnology*. Third Edition. Academic Press, San Diego, CA 1006pp.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED SOURCES ON ALGAL ECOLOGY

Whitten, B.A. and Potts, M. (Editors) 2000. *The Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer Academic Publishers, Boston, MA.

Willen, E. 1991. *Planktonic diatoms - an ecological review*. Algological Studies 62:69-106.

Wood, A.M., Leatham, T., Manhart, J.R. and R.M. McCourt. 1992. *The species concept in phytoplankton ecology.* Journal of Phycology 723-729.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED REFERENCES FOR INTERPRETING ALGAL DATA

Bick, H. 1962. *A review of European methods for the biological estimation of water pollution levels*. WHO/EBL/4:1-27.

Brillouin, L. 1962. *Science and Information Theory*, Second Edition, Academic Press, New York NY.

Cairns, J. 1974. *Indicator species vs. the concept of community structure as an index of pollution.* Water Resources Bulletin 10:338-347.

Cairns, J. 1975. *Critical species, including man, within the biosphere.* Naturwissenschaften 62:193-199.

Cairns, J. et al. 1972. *Pollution related structural and functional changes in aquatic communities with emphasis on freshwater algae and protozoa*. The Proceedings of the Academy of Natural Sciences of Philadelphia 124:79-127.

Carlson, R.E. 1977. *A trophic state index for lakes*. Limnology & Oceanography 22:361-369.

Collins, G.B. and Weber, C.I. 1978. *Phycoperiphyton as indicators of water quality*. Transactions of the American Microscopical Society 97:36-41.

Fjerdingstad, E. 1965. *Some remarks on a new saprobic system. In: Biological Problems in Water Pollution,* 3rd Seminar, 1962, pp 232-235, C.M. Tarzwell, Editor, USDHEW, PHS, Cincinnati, OH.

Fjerdingstad, E. 1971. *Microbial criteria of environmental qualities*. Annual Review of Microbiology 25:563-582.

Hurlbert, S.H. 1971. *The non-concept of species diversity: a critique and alternative parameters.* Ecology 52:577-586.

Keating, K.I. et al. 1975. *Water use techniques. Chapter 3 in: Review of Water Quality - Interpretive Techniques*, J. Orlando and R. Wrightington, (Editors), USEPA and USGS report to CEQ.

Lowe, R.L. 1974. *Environmental Requirements and Pollution Tolerance of Freshwater Diatoms.* EPA-670/4-74-005 USEPA, Cincinnati, OH.

Mackenthun, K.M. 1966. *Biological evaluation of polluted streams*. Journal of the Water Pollution Control Federation 38:241-247.

McIntosh, R.P. 1967. *An index of diversity and the relation of certain concepts to diversity.* Ecology 48:392-404.

Nygaard, G. 1949. *Hydrobiological studies on some Danish ponds and lakes : Part II : The quotient hypothesis and some new or little known phytoplankton organisms*. Kobenhavn I kommission hos Munksgaard.

Odum, H.T. 1956. *Primary reproduction in flowing waters*. Limnology and Oceanography 1:102-117.

Palmer, C.M. 1969. *A composite rating of algae tolerating organic pollution.* Journal of Phycology 5:78-82.

Patrick, R. 1965. *Algae as indicators of pollution.* In: Biological Problems in Water Pollution, 3rd Seminar, 1962, pp 225-231, C.M. Tarzwell (Editor), USDHEW, PHS, Cincinnati, OH.

Patrick, R. 1972. *Aquatic communities as indices of pollution*. In: Indicators of Environmental Quality. W.A. Thomas (Editor) Plenum Press, New York, NY.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED REFERENCES FOR INTERPRETING ALGAL DATA

Patrick, R. 1973. *Use of algae, especially diatoms, in the assessment of water quality*. In: Biological Methods for the Assessment of Water Quality, American Society for Testing and Material STP 528, pp 76-95, ASTM, Phila., Pa.

Patrick, R. and Strawbridge, D. 1963. *Variation in the structure of natural diatom communities*. American Naturalist 98:51-57.

Pielou, E.C. 1966. *The measurement of diversity in different types of biological collections*. Journal of Theoretical Biology 13:131-144.

Pielou, E.C. 1966. *Species diversity and pattern diversity in the study of ecological succession*. Journal of Theoretical Biology 10:370-383.

Pielou, E.C. 1970. *An Introduction to Mathematical Ecology*. Wiley-Interscience, New York, NY

Rawson, D.S. 1956. *Algal indicators of trophic lake types*. Limnology and Oceanography 1:18-25.

Sournia, A. 1978. *Phytoplankton Manual*. United Nations Educational, Scientific and Cultural Organization 337pp.

Stoermer, E.F. 1978. *Phytoplankton assemblages as indicators of water quality in the Laurentian Great Lakes*. Transactions of the American Microscopical Society 97:2-16.

Sweeney, R.A. 1970. *Algae as indicators of pesticides*. Special Report. #4, Great Lakes Laboratory, State University College at Buffalo, NY.

Van Landingham, S.L. 1982. *Guide to the identification, environmental requirements, and pollution tolerance of blue-green algae (Cyanophyta)*. EPA/3-82-073, USEPA.

Weber, C.I. 1973. *Recent developments in the measurement of the response of plankton and periphyton to changes in their environment*. In: Bioassay Techniques and Environmental Chemistry, Glass, G. (Editor) pp 119-138, Ann Arbor Scientic Publishers Ann Arbor, MI.

Wilhm, J.L. and Dorris, T.C. 1968. *Biological parameters for water quality criteria*. Journal of Bioscience and Bioengineering 18: 477-481.

SUPPLEMENT #3: ALGAL ECOLOGY

SELECTED REFERENCES FOR ALGAL TOXICITY

Bartram, J. 2001. *Toxic Cyanobacteria in Water*. World Health Organization.

Carmichael, W. 2001. *Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water.* Water Research Foundation, Denver, CO.

Chorus, I. (editor) 2001. *Cyanotoxins: Occurrence, Causes and Consequences*. Springer, Berlin 357pp.

Chorus, I. and J. Bartram. 1999. *Toxic Cyanobacteria in Water.* E&F Spon, New York, NY.

EPA materials (http://www.epa.gov/nutrient-policy-data/cyanohabs), drinking water guidance, etc.

Falconer I.R. and Humpage A.R. 2005. *Health Risk Assessment of Cyanobacterial (blue-green Algal) toxins in Drinking Water,* International Journal of Environmental Research and Public Health, 2(1), 43-50

Graham, J. L., Jones, J.R.,. Jones, S.B,. Downing, J.A. and Clevenger T.E. 2004. *Environmental factors influencing microcystin distribution and concentration in the Midwestern United States.* Water Resources 38:4395-4404.

Graham J.L, Loftin KA, and Kammon, N. 2009. *Monitoring Recreational Freshwaters.* Lakeline Summer 18-24

The HABHRCA Legislation: /www.gpo.gov/fdsys/pkg/PLAW-113publ124/pdf/PLAW-113publ124.pdf

Hudnell H.K. (Editor) 2008. *Cyanobacterial Harmful Algal Blooms* (ISOC-HAB): State-of-the-Science and Research Needs, New York, NY, Springer Press: Advances in Experimental Medicine and Biology, 619:1-949.

Huisman, J., Mattijs, C.P. and Visser, P. (Editors) 2005. *Harmful Cyanobacteria*. Springer. Norwell, MA 241pp.

Newcombe, G. 2002. *Removal of Algal Toxins from Drinking Water Using Ozone and GAC.* Water Research Foundation Denver, CO.

Rosen, B.H., and St. Amand, A. 2015. *Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities*: U.S. Geological Survey Open-File Report 2015–1164, 44 p.

Watanabe, M.F. 1996. *Toxic Microcystis*. CRC Press, Inc. New York, NY 262pp.

Westrick, J. A. 2003. *Everything a manager should know about algal toxins but was afraid to ask*. Journal of the American Water Works Association 95 (9):26-34.

Yoo, S. 1995. *Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide*. AWWARF, Denver, CO.

SUPPLEMENT #3: ALGAL ECOLOGY

Division	Group	Genus	T&O Producer (Commonly, Sometimes, Not Likely)	Toxin Producer (C, S, N)
BACILLARIOPHYTA	Centric Diatoms	Aulacoseira/Melosira	S	N
BACILLARIOPHYTA	Centric Diatoms	Cyclotella	S	N
BACILLARIOPHYTA	Centric Diatoms	Stephanodiscus	S	N
BACILLARIOPHYTA	Araphid Pennate Diatoms	Asterionella	C	N
BACILLARIOPHYTA	Araphid Pennate Diatoms	Fragilaria/related taxa	S	N
BACILLARIOPHYTA	Araphid Pennate Diatoms	Synedra	S	N
BACILLARIOPHYTA	Araphid Pennate Diatoms	Tabellaria	S	N
BACILLARIOPHYTA	Biraphid Pennate Diatoms	Cymbella	S	N
BACILLARIOPHYTA	Biraphid Pennate Diatoms	Gomphonema/related taxa	S	N
BACILLARIOPHYTA	Biraphid Pennate Diatoms	Nitzschia	S	S
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Actinastrum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Ankistrodesmus	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Botryococcus	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Characium	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Chlorella	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Chlorococcum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Coelastrum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Crucigenia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Dactylococcus	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Deasonia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Dictyosphaerium	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Dispora	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Franceia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Gloeocystis	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Golenkinia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Kirchneriella	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Lagerheimia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Micractinium	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Monoraphidium	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Oocystis	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Pediastrum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Polyedriopsis	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Quadrigula	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Scenedesmus	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Schroederia	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Selenastrum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Sphaerocystis	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Tetraedron	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Tetrastrum	S	N
CHLOROPHYTA	Coccoid/Colonial Chlorophytes	Treubaria	S	N
CHLOROPHYTA	Desmids	Arthrodesmus	S	N
CHLOROPHYTA	Desmids	Closterium	S	N
CHLOROPHYTA	Desmids	Cosmarium	S	N
CHLOROPHYTA	Desmids	Desmidium	S	N
CHLOROPHYTA	Desmids	Euastrum	S	N
CHLOROPHYTA	Desmids	Micrasterias	S	N
CHLOROPHYTA	Desmids	Roya	S	N
CHLOROPHYTA	Desmids	Spirogyra	S	N
CHLOROPHYTA	Desmids	Staurastrum	S	N
CHLOROPHYTA	Desmids	Staurodesmus	S	N

SUPPLEMENT #3: ALGAL ECOLOGY

Division	Group	Genus	T&O Producer (Commonly, Sometimes, Not Likely)	Toxin Producer (C, S, N)
CHLOROPHYTA	Filamentous Chlorophytes	Cladophora	S	N
CHLOROPHYTA	Filamentous Chlorophytes	Hydrodictyon	S	N
CHLOROPHYTA	Filamentous Chlorophytes	Pithophora	S	N
CHLOROPHYTA	Filamentous Chlorophytes	Rhizoclonium	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Carteria	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Chlamydomonas	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Chlorogonium	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Eudorina	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Gonium	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Pandorina	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Platydorina	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Pleodorina	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Pyramichlamys	S	N
CHLOROPHYTA	Flagellated Chlorophytes	Volvox	S	N
CHRYSOPHYTA	Flagellated Chrysophytes	Chrysosphaerella	C	N
CHRYSOPHYTA	Flagellated Chrysophytes	Dinobryon	C	N
CHRYSOPHYTA	Flagellated Chrysophytes	Mallomonas	C	N
CHRYSOPHYTA	Flagellated Chrysophytes	Ochromonas	S	S
CHRYSOPHYTA	Flagellated Chrysophytes	Synura	C	N
CHRYSOPHYTA	Haptophytes	Prymnesium	S	C
CYANOPHYTA	Filamentous Cyanophytes	Arthrospira/Spirulina	S	N
CYANOPHYTA	Filamentous Cyanophytes	Lyngbya	C	C
CYANOPHYTA	Filamentous Cyanophytes	Oscillatoria	C	C
CYANOPHYTA	Filamentous Cyanophytes	Phormidium	C	N
CYANOPHYTA	Filamentous Cyanophytes	Pseudanabaena	C	N
CYANOPHYTA	Filamentous Cyanophytes	Schizothrix	N	S
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Anabaena	C	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Anabaenopsis	C	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Aphanizomenon	C	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Cylindrospermopsis	N	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Cylindrospermum	N	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Hapalosiphon	N	S
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Nodularia	N	S
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Nostoc	C	C
CYANOPHYTA	N-fixing Filamentous Cyanophytes	Raphidiopsis	S	S
CYANOPHYTA	Unicellular/Colonial Cyanophytes	Aphanocapsa	N	S
CYANOPHYTA	Unicellular/Colonial Cyanophytes	Gomphosphaeria	S	N
CYANOPHYTA	Unicellular/Colonial Cyanophytes	Microcystis	C	C
CYANOPHYTA	Unicellular/Colonial Cyanophytes	Synechococcus	N	S
EUGLENOPHYTA	Other Flagellates	Euglena	S	N
EUGLENOPHYTA	Other Flagellates	Lepocinclis	S	N
EUGLENOPHYTA	Other Flagellates	Phacus	S	N
EUGLENOPHYTA	Other Flagellates	Strombomonas	S	N
EUGLENOPHYTA	Other Flagellates	Trachelomonas	S	N
PYRRHOPHYTA	Other Flagellates	Amphidinium	S	N
PYRRHOPHYTA	Other Flagellates	Ceratium	S	N
PYRRHOPHYTA	Other Flagellates	Glenodinium	S	N
PYRRHOPHYTA	Other Flagellates	Gymnodinium	S	N
PYRRHOPHYTA	Other Flagellates	Peridinium	S	N

Note: Recent evidence indicates that Gloeotrichia, an N-fixing filamentous cyanobacterium, produces toxins.

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS

The choices for management include physical, chemical and biological control mechanisms, singly or in combination. These are itemized in the associated table. Examples of capitalization upon key growth and loss processes include:

A. Toxic reaction to chemicals: Copper is a metabolic poison to which many algae react by cellular destruction. Diatoms, chrysophytes and many cyanobacteria are sensitive to copper, but many green algae (most notably the Cladophorales and Chlorococcales) and some cyanobacteria (most notably *Aphanizomenon,* sometimes *Anabaena* and *Phormidium*) can be very resistant to its effects. Alternative forms of copper and peroxide-based algaecides have been developed to affect copper-resistant algae or to minimize toxic effects on certain non-target organisms (e.g., trout, *Daphnia*, or certain desirable native plant species), with varying results.

B. Photosynthesis under changing light levels: The pigment composition of an alga determines its preference for both quality and quantity of light. Although some algae can become heterotrophic (feeding on organic compounds, bacteria, other algae or even animals), most grow poorly in the absence of light, and some grow poorly if certain wavelengths of light are reduced in intensity. Use of dyes or covers can reduce certain algal growths or alter the competitive balance to shift species composition. Blue-greens, the chrysophyte *Synura* and certain filamentous green algae tend to tolerate low light levels best, however, and these are among the major problem algae, so alteration of light levels alone is rarely sufficient to achieve the desired level of control.

C. Buoyancy regulation: Increasing temperature lowers the viscosity of water and increases settling rates of algae, and addition of polymers or other settling agents may increase the settling rate of affected algae. Buoyancy compensation mechanisms by certain bluegreens (gas vesicles) and flagellated algal forms (motility) minimize impacts of increasing settling rate, however. Water circulation may disrupt buoyancy compensation mechanisms, but circulatory effects on light and photosythesis or simple redistribution of algal cells throughout the water column appear to be stronger effects of that technique. Strong percussion (underwater explosion) is known to collapse the gas vesicles in bluegreens, but also stuns or kills fish.

D. Wash-out: Although algae grow fast, high flushing rates in an aquatic system will limit accumulation of biomass. If a lake naturally flushes about every two weeks, blooms will be rare. Flushing rate can be increased by the addition of more water. If that water is of low nutrient content, dilution may also be a factor in controlling algal growths. Acquiring an adequate supply of water, preferably low nutrient water, often limits application of this approach.

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS

E. Predation (Grazing): Zooplankton depend largely on algae for food, and a population of large-bodied herbivorous zooplankters, most notably the Cladoceran *Daphnia*, can filter the entire volume of a lake more rapidly than most algae can grow. *Daphnia* are minimally selective about what they eat, and the larger the body, the larger the particle size that can be consumed and the greater the filtering rate (related to cube of body length). Some strains of bluegreens are toxic to zooplankton, and many of the small gelatinous greens of the order Chlorococcales can pass through a zooplankton gut undigested, but intense water filtration by zooplankton can be an effective means for minimizing algal biomass. Unfortunately, *Daphnia* are also the preferred food of many small fish, which can decimate the population and limit grazing control of algae. This biomanipulative approach is a question of ecological balance, which can be difficult to maintain. However, maintenance of the greatest possible biomass of large bodied *Daphnia* will generally result in the maximum water clarity possible at the overall level of system fertility.

F. Nutritional requirements: Control of a variety of nutrients can result in either control of algal biomass or shifts in taxonomic composition. Trace nutrients, such as iron, calcium, magnesium, sulfur and potassium, may limit productivity in some cases, and substantial silica is essential to the growth of most diatoms. Carbon can be a limiting nutrient is some systems, but most management schemes target phosphorus or nitrogen, the primary growth nutrients. Even then, nitrogen availability can be difficult to decrease, given its abundance as a gas and the ability of certain blue-greens to use this source of nitrogen (mainly through fixation in heterocysts). Consequently, control of algal biomass normally relies on control of phosphorus availability.

Phosphorus control is best achieved by preventing its entry into the lake with watershed management practices. Once phosphorus is in the system it may be controlled through such techniques as aeration (limiting recycling from the sediments), selective withdrawal (removing differentially phosphorus-rich water), or inactivation (binding to “anti-fertilizer” compounds such as aluminum salts, which then settle out of the water column). Addition of water low in phosphorus (dilution) or removal of phosphorus-laden sediments (dredging) can also reduce phosphorus availability.

Beyond the absolute quantity of essential nutrients, control can sometimes be achieved by altering the relative quantities of key nutrients. Algae prefer nutrients in certain ratios, the most studied of which is the N:P ratio. Chlorococcalean greens have one of the highest preferred ratios, often around 30:1 by weight. Nitrogen-fixing bluegreens have the lowest ratios, typically around 7:1 by weight. By removing or adding nutrients to alter the effective ratio, shifts in taxonomic composition can be achieved. If this results in dominance by forms that are more edible to zooplankton or have higher settling rates, some control of biomass may also be achieved as an indirect effect. Addition of nitrogen can sometimes minimize formation of blue-green surface scums, and an infusion of silica can prolong the typical spring period of diatom dominance.

SUPPLEMENT #4: ALGAL MANAGEMENT

10 AXIOMS FOR MANAGEMENT OF ALGAE

1. Where light and nutrients are sufficient and toxic substances are limited, algae will grow

- Phosphorus >0.01 mg/L and nitrogen >0.3 mg/L can support blooms.
- Phosphorus >0.05 mg/L and nitrogen >1.0 mg/L will usually support blooms.
- Phosphorus is critical to the quantity of algae present, up to about 0.10 mg/L.
- Nitrogen is critical to the types of algae present, and sometimes the quantity.
- Very little light is necessary for some species of algae to bloom; tolerance of low light for an extended time period is common.
- Metals and some organic compounds are the primary toxicants for algae.

2. One factor will control the abundance of any given alga, but that factor can vary over time and among algae

- Some blue-greens can fix nitrogen, but require elements not needed by other algae.
- Diatoms need much more silica than other algae, and are also less buoyant.
- Succession of algae can be triggered by changing control factors.
- Control of the whole algal community by one factor occurs at extremes (e.g. very low P or high copper).

3. Nutrient ratios are major determinants of the type of algae present

- N:P:Si ratio is most influential, but trace nutrients can have an effect as well.
- Blue-greens which can fix N thrive at low N:P ratios (<15:1 by weight).
- Most greens prefer high N:P ratios (>30:1 by weight).
- Diatoms require high Si, but occur at a wide range of N:P ratios.
- Carbon availability can be important at very high N and P.
- Light and temperature can also be important determinants of algal assemblage composition.

4. Productivity and biomass are related but separate concepts

- Productivity is a growth process.
- Biomass is the net result of growth and loss processes.
- High productivity leads to high biomass if loss processes are not adequate to maintain balance.

5. Diversity of algal adaptations may defeat any control strategy except maintaining low phosphorus

- N fixation
- Buoyancy regulation
- Auxiliary pigments
- Heterotrophy
- Anti-grazing mechanisms
- Copper resistance

6. The most effective algal control is achieved through reduction of external and internal phosphorus loading

- P can be made to limit productivity most reliably.
- Essential to determine relative magnitude of sources of P.
- May require multiple techniques and extended timeframe.

SUPPLEMENT #4: ALGAL MANAGEMENT

10 AXIOMS FOR MANAGEMENT OF ALGAE

7. High grazing pressure yields the lowest algal biomass per unit of fertility

- Large-bodied, herbivorous, Cladoceran zooplankton (*Daphnia*) at high biomass can limit algal biomass.
- Algal adaptation can overcome grazing pressure if nutrients are sufficient.

8. Algaecides should only be used until growth processes can be controlled

- Algaecides can provide short-term control and can prevent blooms if applied at the proper time.
- Algaecides do not provide long-term control and can have adverse side effects.

9. The "No Action" alternative carries substantial unstated costs

- Treatment costs are proportional to algal density in many cases.
- Use impairment can be translated into monetary value.
- Lost property value has been documented and yields a lower tax base.

10. The cost of control should be evaluated on a long-term basis

- Short-term cost is more variable among techniques than long-term cost.
- Control is rarely a one or two year effort.
- Capital, operational and maintenance costs apply in different time frames.

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

(Adapted from Wagner 2001)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
WATERSHED CONTROLS			
1) Management for nutrient input reduction	♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal nutrition ♦ Creates sustainable limitation on algal growth ♦ May control delivery of other unwanted pollutants to lake ♦ Facilitates ecosystem management approach which considers more than just algal control	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-lake management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae
1a) Point source controls	♦ More stringent discharge requirements ♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Often provides major input reduction ♦ Highly efficient approach in most cases ♦ Success easily monitored	♦ May be very expensive in terms of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases
1b) Non-point source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, as with no phosphate fertilizer	♦ Removes source ♦ Limited or no ongoing costs	♦ May require purchase of land or activity ♦ May be viewed as limitation of "quality of life" ♦ Usually requires education and gradual implementation
1c) Non-point source pollutant trapping	♦ Capture of pollutants between source and lake ♦ May involve drainage system alteration ♦ Often involves wetland treatments (detention/infiltration) ♦ May involve stormwater collection and treatment as with point sources	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed ♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance ♦

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
IN-LAKE PHYSICAL CONTROLS			
2) Circulation and destratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ May disrupt growth of blue-green algae ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ May reduce internal loading of phosphorus	♦ May spread localized impacts ♦ May lower oxygen levels in shallow water ♦ May promote downstream impacts
3) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts
4) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Discharge of a large portion of lake water with nutrients at the highest level of the year can result in a net loss of nutrients from the lake. ♦ Refill by lower nutrient water from a well-managed watershed, or just high spring flushing, can reset the lake to a lower nutrient level. ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well ♦ Long-term, low-cost approach to managing internal load	♦ Possible impacts on non-target resources ♦ Possible impairment of water supply ♦ Alteration of downstream flows and winter water level ♦ May result in greater nutrient availability if flushing inadequate ♦ Usually a very slow way to lower internal loading (10-30 year timeframe typical)

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
5) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging
5a) "Dry" excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Rarely truly a dry operation; tends to be messy ♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging
5b) "Wet" excavation	♦ Lake level may be lowered, but sediments not substantially exposed ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Requires least preparation time or effort, tends to be least cost dredging approach ♦ May allow use of easily acquired equipment ♦ May preserve aquatic biota	♦ Usually creates extreme turbidity ♦ Normally requires intermediate containment area to dry sediments prior to hauling ♦ May disrupt ecological function ♦ Disrupts many uses
5c) Hydraulic removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle coarse or debris-laden materials ♦ Requires sophisticated and more expensive containment area
6) Light-limiting dyes and surface covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
6.a) Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Produces appealing color ♦ Creates illusion of greater depth	♦ May not control surface bloom-forming species ♦ May not control growth of shallow water algal mats ♦ Alters thermal regime
6.b) Surface covers	♦ Opaque sheet material applied to water surface	♦ Minimizes atmospheric and wildlife pollutant inputs	♦ Minimizes atmospheric gas exchange ♦ Limits recreational use
7) Mechanical removal	♦ Filtering of pumped water for water supply purposes ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability for use with high algal densities ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target aquatic life
8) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ Complements other techniques such as drawdown or aeration ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May eliminate colder thermal layer that supports certain fish ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal
9) Sonication	♦ Sound waves disrupt algal cells	♦ Supposedly affects only algae (new technique) ♦ Applicable in localized areas	♦ Uncertain effects on non-target organisms ♦ May release cellular toxins or other undesirable contents into water column
IN-LAKE CHEMICAL CONTROLS			

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
10) Hypolimnetic aeration or oxygenation	♦ Addition of air or oxygen at varying depth provides oxic conditions ♦ May maintain or break stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions promote binding/sedimentation of phosphorus ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Build-up of dissolved iron, manganese, sulfide, ammonia and phosphorus reduced	♦ May accidentally disrupt thermal layers important to fish community ♦ Theoretically promotes supersaturation with gases harmful to fish ♦ Biota may become dependent on continued aeration
11) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column, normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target species ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity ♦ Possible recycling of nutrients
11a) Forms of copper	♦ Cellular toxicant, suggested disruption of photosynthesis, nitrogen metabolism, and membrane transport ♦ Applied as wide variety of liquid or granular formulations, often in conjunction with chelators, polymers, surfactants or herbicides	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Possible toxicity to aquatic fauna ♦ Ineffective at colder temperatures ♦ Accumulation of copper in system ♦ Resistance by certain green and blue-green nuisance species ♦ Rupturing of cells releases nutrients and toxins
11b) Synthetic organic herbicides	♦ Absorbed or membrane-active chemicals which disrupt metabolism ♦ Causes structural deterioration	♦ Used where copper is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Possible toxicity to aquatic fauna (varying degrees by dose and formulation) ♦ Time delays on water use
11c) Oxidants (mostly peroxides)	♦ Disrupts most cellular functions, tends to attack membranes ♦ Applied most often as a liquid.	♦ Potential selectivity against blue-greens ♦ Moderate control of thick algal mats, used where copper alone is ineffective ♦ Rapid action	♦ Older formulations tended to have high toxicity to some aquatic fauna ♦ Limited field experience with new formulations

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
12) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the lake ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment ♦ Permanence of binding varies by binder in relation to redox potential and pH	♦ Can provide rapid, major decrease in phosphorus concentration in water column ♦ Can minimize release of phosphorus from sediment ♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement	♦ Possible toxicity to fish and invertebrates, mainly by aluminum at low or high pH ♦ Possible release of phosphorus under anoxia (with Fe) or extreme pH (with Ca) ♦ May cause fluctuations in water chemistry, especially pH, during treatment ♦ Possible resuspension of floc in shallow areas ♦ Adds to bottom sediment, but typically an insignificant amount
13) Sediment oxidation	♦ Addition of oxidants, binders and pH adjusters to oxidize sediment ♦ Binding of phosphorus is enhanced ♦ Denitrification is stimulated	♦ Can reduce phosphorus supply to algae ♦ Can alter N:P ratios in water column ♦ May decrease sediment oxygen demand	♦ Possible impacts on benthic biota ♦ Longevity of effects not well known ♦ Possible source of nitrogen for blue-green algae
14) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
15) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients ♦ Addition of non-limiting nutrients can change composition of algal community ♦ Processes such as settling and grazing can then reduce algal biomass (productivity can actually increase, but standing crop can decline)	♦ Can reduce algal levels where control of limiting nutrient not feasible ♦ Can promote non-nuisance forms of algae ♦ Can improve productivity of system without increased standing crop of algae	♦ May result in greater algal abundance through uncertain biological response ♦ May require frequent application to maintain desired ratios ♦ Possible downstream effects
IN-LAKE BIOLOGICAL CONTROLS			
16) Enhanced grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of large herbivorous zooplankton, or stocking with phytophagous fish	♦ May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels ♦ Can convert unwanted biomass into desirable form (fish) ♦ Harnesses natural processes to produce desired conditions	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms
16.a) Herbivorous fish (not permitted in MA)	♦ Stocking of fish that eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking rate	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefited and bloom
16.b) Herbivorous zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be high ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ Larger or toxic algal forms may be benefited and bloom

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
17) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	♦ Reduces turbidity and nutrient additions from this source ♦ May restructure fish community in more desirable manner	♦ Targeted fish species are difficult to eradicate or control ♦ Reduction in fish populations valued by some lake users (human/non-human)
18) Pathogens	♦ Addition of inoculum to initiate attack on algal cells ♦ May involve fungi, bacteria or viruses	♦ May create lakewide "epidemic" and reduction of algal biomass ♦ May provide sustained control through cycles ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ May promote resistant nuisance forms ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain
19) Competition and allelopathy	♦ Plants may tie up sufficient nutrients to limit algal growth ♦ Plants may create a light limitation on algal growth ♦ Chemical inhibition of algae may occur through substances released by other organisms	♦ Harnesses power of natural biological interactions ♦ May provide responsive and prolonged control	♦ Some algal forms appear resistant ♦ Use of plants may lead to problems with vascular plants ♦ Use of plant material may cause depression of oxygen levels
19a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients ♦ Plants can exude allelopathic substances which inhibit algal growth ♦ Portable plant "pods" , floating islands, or other structures can be installed	♦ Productivity and associated habitat value can remain high without algal blooms ♦ Can be managed to limit interference with recreation and provide habitat ♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs	♦ Vascular plants may achieve nuisance densities ♦ Vascular plant senescence may release nutrients and cause algal blooms ♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes
19b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities	♦ Vascular plants can be more easily harvested than most algae ♦ Many floating species provide valuable waterfowl food	♦ At the necessary density, floating plants likely to be a recreational nuisance ♦ Low surface mixing and atmospheric contact promote anoxia

SUPPLEMENT #4: ALGAL MANAGEMENT

MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
19c) Addition of barley straw	♦ Input of barely straw can set off a series of chemical reactions which limit algal growth ♦ Release of allelopathic chemicals can kill algae ♦ Release of humic substances may bind phosphorus	♦ Materials and application are relatively inexpensive ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors ♦ Depression of oxygen levels may result ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

Andersson, G. 1988. *Restoration of Lake Trummen, Sweden: effects of sediment removal and fish manipulation*. In: Balvay, G. (editor). Eutrophication and Lake Restoration. Water Quality and Biological Impacts, Thonon-les-Bains.

Axler, R. 1988. *Fish aid - the Lake Mead fertilization project*. Lake and Reservoir Management 4:125-135.

Babin, J., Prepas, E., Murphy T. and Hamilton, H. 1989. *A test of the effects of lime on algal biomass and total phosphorus concentrations in Edmonton stormwater retention lakes.* Lake and Reservoir Management 5:129-135.

Barko, J., James, W.F., Taylor, W.D. and McFarland, D.G. 1990. *Effects of alum treatment on phosphorus and phytoplankton dynamics in Eau Galle Reservoir: A synopsis*. Lake and Reservoir Management 6:1-8.

Barrett, P., Curnow, J. and Littlejohn, J. 1996. *The control of diatoms and cyanobacterial blooms in reservoirs using barley straw.* In: Caffrey, J. and Barrett P. (editors). Management and Ecology of Freshwater Plants, Proceedings of the 9th International Symposium on Aquatic Weeds, Kluwer Academic Publishers, London.

Barroin, G. 1980. *Sediment treatment for phosphorus inactivation*. In: Restoration of Lakes and Inland Waters. EPA 440/5-81-010 USEPA, Washington, DC.

Benndorf, J. 1989. *Food web manipulation as a tool in water quality management*. Journal of Water Supply, Research and Technology 38:296-304.

Brandt, S. 1998. *Impacts of alewife introduction on plankton and water quality*. Presented at the NEC NALMS Conference, June 1998, UNH, Durham, NH.

Carpenter, S.R. et. al. 1995. *Biological Control of Eutrophication in Lakes.* Environmental Science Technology 29(3):784-786.

Center for Watershed Protection. 2003. *Impacts of Impervious Cover on Aquatic Systems.* Watershed Protection Research Monograph #1, CWP, Ellicot City, MD.

Claytor, R. and Schueler, T. 1996. *Design of Storm Water Filtering Systems*. Center for Watershed Protection, Ellicot City, MD. Center for Watershed Protection, Ellicot City, MD.

Connor, J. and Martin, M. 1989. *An assessment of sediment phosphorus inactivation*, Kezar Lake, NH, Water Resources Bulletin 25:845-853.

Connor, J. and Martin, M. 1989. *An Assessment of Wetlands Management and Sediment Phosphorus Inactivation.* Kezar Lake, NH, NH Dept. of Environmental Services, Concord, NH.

Cooke, G.D. and Carlson, R.E. 1989. *Reservoir Management for Water Quality and THM Precursor Control*. AWWA Research Foundation, Denver, CO.

Cooke, G.D., Heath, R.T. Kennedy, R.H. and McComas, M.R. 1982. *Change in lake trophic state and internal phosphorus release after aluminum sulfate application*. Water Resources Bulletin 18(4):699-705.

Cooke, G.D., et al 1993. *Effectiveness of Al, Ca, and Fe salts for control of internal phosphorus loading in shallow and deep lakes*. Hydrobiologia 253:323-335.

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

Cooke, G.D., Welch, E.B., Peterson, S.A. and Nichols, S.A. 2005. *Restoration and Management of Lakes and Reservoirs*. CRC Press, Boca Raton, FL. 591pp.

Dennis, J., Noel, J., Miller, D. and Eliot, C. 1989. *Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development.* Maine Department of Environmental Protection, Augusta, Maine.

Dettmers, J. and Stein, R. 1996. *Quantifying linkages among gizzard shad, zooplankton and phytoplankton in reservoirs*. Transactions of the American Fisheries Society. 125:27-41.

Dominie, D.R. 1980. *Hypolimnetic aluminum treatment of softwater Annabessacook Lake.* Maine Department of Environmental Protection, Augusta, Maine.

Dunst, R., et al. 1974. *Survey of Lake Rehabilitation Techniques and Experiences*. Technical Bulletin #75, Wisconsin DNR, Madison, WI.

Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration: Principles, Processes and Practice*s. USEPA, Washington, DC.

Garrison, P.J. and Knauer, D.R. 1984. *Long-term evaluation of three alum treated lakes*. In: Lake and Reservoir Management. EPA/440/5/84-001, pp. 513-517.

Hanson, M.J. and Stefan, H.G. 1984. *Side effects of 58 years of copper sulfate treatment in the Fairmont Lakes, Minnesota*. Water Resources Bulletin 20:889-900.

Harper, H.H., Herr, J.E. and Livingston, E. 1999. *Alum treatment of stormwater: The first ten years*. Pages 159-180 in James, W. (editor). Modeling Urban Water Systems, Computational Hydraulics International, Guelph, Ontario.

Harriger, R.D. and Steelhammer, J.C. 1989. *Alzheimer's Disease, Aluminum and Drinking Water Treatment: A Review*. General Chemical Corporation, Syracuse, NY

Haynes, R.C. 1988. *An Introduction to the Blue-green Algae (Cyanobacteria) with an Emphasis on Nuisance Species*. NALMS, Washington, DC.

Heufelder, G. and Rask, S. 1997. *A Compendium of Information on Alternative Onsite Septic System Technology in Massachusetts*. A special issue of Environment Cape Cod, Barnstable County Department of Health and the Environment, Barnstable, MA.

Holaday, S. 1997. *Wisconsin's Forestry Best Management Practices for Water Quality: Field Manual*. Wisconsin DNR, Madison, WI.

Holdren, G.C., Jones, W. and Taggart, J. 2001. *Managing Lakes and Reservoirs*. North American Lake Management Society and Terrene Inst. in cooperation with the Office of Water, Assessment and Watershed Protection Division, USEPA/NALMS, Madison, WI.

Hosper, H. and Meijer, M-L. 1993. *Biomanipulation, will it work for your lake?* Ecology Engineering 2:63-72.

Jacoby, J.M., Gibbons, H.L., Stoops, K.B., and Bouchard, D.D. 1994. *Response of a shallow, polymictic lake to buffered alum treatment*. Lake and Reservior Management 10:103-112.

Kadlec, R. and Knight, R. 1996. *Treatment Wetlands.* CRC Press, Boca Raton, FL.

Kay, S.H. 1996. *Barley straw for algae control - a North Carolina experience*. Aquatics 18:9-10.

Kenefick, S.L., Hrudey, S.E., Peterson, H.G. and Prepas, E.E. 1993. *Toxin release from Microcystis aeruginosa after chemical treatment*. Water Science Technology 27:433-440.

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

Kennedy, R.H. and Cooke, G.D. 1982. *Control of lake phosphorus with aluminum sulfate: dose determination and application techniques.* Water Resources Bulletin 18(3):389-395.

Kilham, P. 1971. *A hypothesis concerning silica and the freshwater planktonic diatoms*. Limnology & Oceanography 16:10-18.

Kishbaugh, S., Bloomfield, J.and Saltman, A. 1990. *Diet For a Small Lake*. New York Department of Environmental Conservation and the Federation of Lake Associations, Inc., Albany and Rochester, NY.

Kortmann, R., Knoecklein, G.W. and Bonnell, C.H. 1994. *Aeration of stratified lakes: Theory and practice*. Lake and Reservior Management 8:99-120.

Krishnan, S. 1988. *The case against aluminum*. Canadian Research 21(3):32-35.

KVA. 1991. *Reverse Layering, An Alternative Approach to Dredging for Lake Restoration.* Technical Report, Research and Demonstration Program, MDEP, Boston, MA.

Lathrop, R.C., Carpenter, S.R. and Robertson, D.M. 1999. *Summer water clarity responses to phosphorus, Daphnia grazing, and internal mixing in Lake Mendota*. Limnology & Oceanography 44:137-146.

Lorenzen, M.W. and Fast. A.W. 1977. *A Guide to Aeration/Circulation Techniques for Lake Management.* EPA-600/3-77-004. USEPA, Washington, DC.

Mattson, M., Godfrey, P., Barletta R. and Aiello, A. with Wagner, K. (editor). 2004. *Generic Environmental Impact for Eutrophication and Aquatic Plant Management in Massachusetts*. MADEP/MADCR, Boston, MA.

McComas, S. 1993. *Lake Smarts: The First Lake Maintenance Handbook*. Terrene Institute/USEPA, Washington, DC.

McKnight, D.M., Chisholm, S.W. and Harleman, D.R.F. 1983. *CuSO4 treatment of nuisance algal blooms in drinking water reservoirs.* Environmental Management 7(4):311-320.

McQueen, D.J., Lean, D.R.S., and Charlton, M.N. 1986. *The effects of hypolimnetic aeration on iron-phosphorus interactions*. Water Research 20:1129-1135.

McQueen, D.J., Post, J.R. and Mills, E.L. 1986. *Trophic relationships in freshwater pelagic ecosystems*. Canadian Journal of Fisheries and Aquatic Sciences 43:1571-1581.

Meijer, M-L., et al. 1994. *The consequences of a drastic fish stock reduction in the large and shallow Lake Wolderwijd, the Netherlands*. Hydrobiologia 275/276:31-42.

Meijer, M-L., et al 1994. *Long-term responses to fish-stock reduction in small shallow lakes: interpretation of five-year results of four biomanipulation cases in the Netherlands and Denmark*. Hydrobiologia 275/276:457-466.

Mitchell, A. and Baldwin, D. 1998. *Effects of desiccation/oxidation on the potential for bacterially mediated pre- release from sediments*. Limnology & Oceanography 43:481-487.

Murphy, T., Prepas, E.E., Lim, J.T., Crosby, J.M. and Walty, D.T. 1990. *Evaluation of calcium carbonate and calcium hydroxid treatment of prairie drinking water dugouts*. Lake and Reservior Management 6:101-108.

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

New Hampshire Department of Environmental Services. 1994. *Best Management Practices to Control Non-Point Source Pollution: A Guide for Citizens and Town Officials*. NHDES-WSPCD – 94-2, NHDES, Concord, NH.

Nurnberg, G. 1987. *Hypolimnetic withdrawal as a lake restoration technique.* Journal of Environmental Engineering Division, ASCE 113:1006-1017.

Payne, F.E., Laurin, C.R., Thornton, K. and Saul, G. 1991. *A Strategy for Evaluating In-Lake Treatment Effectiveness and Longevity*. NALMS, Alachua, FL.

Peterson, S.A. 1981. *Sediment Removal as a Lake Restoration Technique*. EPA 600/3-81-013. USEPA, Washington, DC.

Prepas, E.E., et al 1990. *Reduction of phosphorus and chlorophyll a concentrations following CaCO3 and Ca(OH)2 additions to hypereutrophic Figure Eight Lake, Alberta*. Environmental Science and Technology 24:1252-1258.

Ridge, I. and Pillinger, J. 1996. *Towards understanding the nature of algal inhibitors from barley straw*. In: Caffrey, J. and Barrett, P. (editors) Management and Ecology of Freshwater Plants, Proceedings of the 9th International Symposium on Aquatic Weeds, Kluwer Academic Publishers, London.

Ripl, W. 1976. *Biochemical oxidation of polluted lake sediment with nitrate - a new lake restoration method*. Ambio 5:132-135.

Ripl, W. 1980. *Lake restoration methods developed and used in Sweden*. In: Restoration of Lake and Inland Waters: Proc. of an International Symposium on Inland Waters and Lake Protection, EPA 440/5-81-010, USEPA, Washington, DC.

Robbins, R.W., Glicker, J.L., Bloem, D.M. and Niss B.M. 1991. *Effective Watershed Management for Surface Water Supplies*. AWWA Research Foundation, Denver, CO. 401pp.

Rohm, C.M., Omernik, J.M. and Kiilsgaard, C.W. 1995. *Regional patterns of total phosphorus in lakes of the northeastern United States*. Lake and Reservior Management 11:1-14.

Sage, K. 1990. *Implementation Strategies for Lake Water Quality Protection: A Handbook of Model Ordinances and Non-Regulatory Techniques for Controlling Phosphorus Impacts from Development*. North Kennebec Regional Planning Commission, Kennebec, ME.

Scheffer, M., Hosper, S.H., Meijer, M-L., Moss, B. and Jeppeson, E. 1993. *Alternative equilibria in shallow lakes.* Trends in Ecology and Evolution 8:275-279.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Center for Watershed Protection, Ellicot City, MD.

Schueler, T., Kumble P. and Heraty, M. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Metropolitan Washington Council of Governments, Washington, DC.

Shapiro, J. 1990. *Biomanipulation: The next phase - Making it stable*. Hydrobiologia 200/201:13-27.

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

Shapiro, J. 1990. *Current beliefs regarding dominance by blue-greens: The case for the importance of CO_2 and pH.* Verhandlungen des Internationalen Verein Limnologie 24:38-54.

Shapiro, J., LaMarra, V. and Lynch M. 1975. *Biomanipulation: An ecosystem approach to lake restoration.* In: Brezonik, P.L. and Fox, J.L. (editors). Symposium on Water Quality Management and Biological Control. University FL, Gainesville.

Shapiro, J. and Wright, D. 1984. *Lake restoration by biomanipulation: Round Lake, MN, the first two years*. Freshwater Biology 14:371-383.

Sharpley, A.N., et al. 1994. *Managing agricultural phosphorus for protection of surface waters: Issues and options*. Journal of Environmental Quality 23:437-451.

Smeltzer, E. 1990. *A successful alum/aluminate treatment of Lake Morey, VT.* Lake and Reservoir Management 6:9-19.

Smith, V.H. 1983. *Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton*. Science 221:669-671.

Spencer, D.A. 1984. *Influence of aquashade on growth, photosynthesis, and phosphorus uptake of microalgae.* Journal of Aquatic Plant Management 22:80-84.

Swann, C. 2001. *The Influence of Septic Systems at the Watershed Level*. Watershed Protection Techniques 3:821-834.

Tilman, D. 1982. *Resource Competition and Community Structure*. Princeton University Press, Princeton, NJ.

UNEP. 1999. *Survey of Residential Nutrient Behavior*. Center for Watershed Protection, Ellicot City, MD.

USDA-NRCS and MA Community Assistance Partnership. 1998. *Innovative and Alternative On-Site Wastewater Technologies*. USEPA, Boston, MA.

USEPA. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters*. EPA 840-B-92-002. United States Environmental Protection Agency, Washington, DC.

USEPA. 1999. *Preliminary Data Summary of Urban Storm Water Best Management Practices*. EPA-821-R-99-012. USEPA, Washington, DC.

USEPA. 2002. *Onsite Wastewater Treatment Systems Manual*. EPA/625/R-00/008. USEPA, Washington, DC.

Wagner, K.J. 1986. *Biological management of a pond ecosystem to meet water use objectives.* Lake and Reservior Management 2:53-61.

Wagner, K.J. 2004. *Practical Lake Management in Massachusetts: A Companion Guide to the GEIR for Eutrophication and Aquatic Plant Management in Massachusetts.* MADEP/MADCR, Boston, MA.

Wagner, K.J. and Oglesby, R.T. 1984. *Incompatibility of common lake management objectives.* In: Lake and Reservoir Management. EPA 440/5-84-001, USEPA, Washington, DC.

Walker, W., Westerberg, C.E., Schuler, D.J. and Bode, J.A. 1989. *Design and evaluation of eutrophication control measures for the St. Paul water supply*. Lake and Reservior Management 5:71-83.

SUPPLEMENT #4: ALGAL MANAGEMENT

SELECTED REFERENCES FOR THE CONTROL OF ALGAE

Welch, E.B., Brenner, M.V. and Carlson, K.L. 1984. *Control of algal biomass by inflow nitrogen*. In: Lake and Reservoir Management. p 493-497. EPA-440/5-84-001, US Environmental Protection Agency, Washington, D.C.

Welch, E.B. and Cooke, G.D. 1999. *Effectiveness and longevity of phosphorus inactivation with alum*. Lake and Reservior Management. 15:5-27.

Welch, E.B., DeGasperi, C.L., Spyridakis, D.E. and Belnick, T.J. 1988. *Internal phosphorus loading and alum effectiveness in shallow lakes.* Lake and Reservior Management 4:27-33.

Welch, E.B. and Patmont, C.R. 1980. *Lake restoration by dilution*: Moses Lake, Washington. Water Resources 14:1317-1325.

Welch, E.B. and Schrieve, G.D. 1994. *Alum treatment effectiveness and longevity in shallow lakes*. Hydrobiologia 276:423-431.

Welsh, D.J. 1991. *Riparian Forest Buffers. Function and Design for Protection and Enhancement of Water Resources*. USDA, Radnor, PA, Na-PR-07-91, 20pp.

Westerdahl, H.E. and Getsinger, K.D. (Editors) 1988. *Aquatic Plant Identification and Herbicide Use Guide. Volume 1: Aquatic Herbicides and Application Equipment*. Waterways Experiment Station, Corps of Engineers, Vicksburg, MS.

Westerdahl, H.E. and Getsinger, K.D. (Editors) 1988. *Aquatic Plant Identification and Herbicide Use Guide. Volume 2: Aquatic Plants and Susceptibility to Herbicides*. Waterways Experiment Station, Corps of Engineers, Vicksburg, MS.

Willenbring, P., Miller, M. and Weidenbacher, W. 1984. *Reducing sediment phosphorus release rates in Long Pond through the use of calcium nitrate*. In: Lake and Reservoir Management, EPA 440/5-84-001, USEPA, Washington, DC.

Winer, R. 2000. *National Pollutant Removal Performance Database for Storm Water Treatment Practices, 2nd Edition*. Center for Watershed Protection, Ellicot City, MD.

Wisconsin Department of Agriculture and Trade and Consumer Protection. 1989. *Best Management Practices for Wisconsin Farms*. WDATCP, Madison, WI.

Wisconsin Department of Natural Resources. 1989. *Environmental Assessment of Aquatic Plant Management* (NR 107) Program. Wisconsin DNR, Madison, WI.

Wisconsin Department of Natural Resources. 1997. *Wisconsin's Forestry BMPs for Water Quality: A Field Manual for Loggers, Landowners and Land Managers*. Wisconsin DNR, Madison, WI.

Wisconsin Department of Natural Resources. 1997. *Wisconsin's Forestry BMPs for Water Quality: The 1995-1997 BMP Monitoring Report*. Wisconsin DNR, Madison, WI.

Wynn, E. and Langeland, K. 1996. *Barley straw for algae control*. Aquatics 18:4-6.