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Harold G. Marshall
Old Dominion University, hmarshal@odu.edu

Lubomira Burchardt

Richard Lacouture

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A review of phytoplankton composition within Chesapeake Bay and its tidal estuaries

HAROLD G. MARSHALL[1]*, LUBOMIRA BURCHARDT[2] AND RICHARD LACOUTURE[3]

[1]DEPARTMENT OF BIOLOGICAL SCIENCES, OLD DOMINION UNIVERSITY, NORFOLK, VA 23529-0266, USA, [2]DEPARTMENT OF HYDROBIOLOGY, COLLEGIUM BIOLOGICUM, ADAM MICKIEWICZ UNIVERSITY, 61-614 POZNAN, POLAND AND [3]MORGAN STATE UNIVERSITY ESTUARINE RESEARCH CENTER, ST. LEONARD, MD 20685, USA

*CORRESPONDING AUTHOR: hmarshal@odu.edu

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Based on a continuous 20-year data base of monthly sampling in Chesapeake Bay and tidal regions of its major tributaries, 1454 phytoplankton taxa have been identified in these waters. They represent a diverse assemblage of species with a dominant diatom flora throughout the year, in addition to large seasonal representation by chlorophytes, cyanobacteria, cryptophytes and dinoflagellates. Included among this flora were 34 potential harmful or toxin producing species. The phytoplankton compositions associated with the seasonal successional patterns are discussed, in addition to characterizing the dominant floral relationships, with comparison to early composition records within the Bay. Several of the present day most common taxa were similar to those reported in sediment cores from the Bay dating to periods prior to European settlement. Comparison with collections made ~8 decades ago (1916–1922) within Chesapeake Bay indicated several of the same dominant flora remain dominant today; however, their cell concentrations are now significantly greater along with an increased diversity of species compared with these earlier studies.

INTRODUCTION

The Chesapeake Bay is the largest estuary in the United States. Located along a north–south orientation (~320 km) of eastern United States, it is a partially mixed estuary with a surface area of 6.5×10^3 km^2 and a mean depth of 8.42 m (Schubel and Pritchard, 1987). The climate is moderate with an average annual temperature of ~14°C and average rainfall of ~106–116 cm annually. It possesses dynamic patterns of internal transport that are influenced by the amount of river and coastal waters entering the Bay. Along its north–south axis, salinity ranges between tidal freshwater (salinity <0.5) in its northern sectors and upstream regions of its tidal tributaries to polyhaline (salinity >18) conditions at the entrance of the Bay. Salinity within the Bay will vary vertically with a less saline upper stratum that is separated by an often seasonally strong pycnocline above the higher salinity bottom waters. Pritchard (Pritchard, 1952) indicated that there is a net surface flow seaward out the Bay and a net bottom flow of higher salinity waters entering the Bay. The magnitude of these water movements will vary in response to tidal action, major storm events and other conditions that influence flow within the system. These conditions in turn will influence daily and seasonal changes in the vertical stratification and homogeneity of the water column. The phytoplankton in these waters is represented by an assemblage of freshwater, estuarine and neritic taxa (Marshall, 1980, 1994; Marshall and Burchardt, 1998, 2003, 2004a).

The earliest records of phytoplankton in Chesapeake Bay come from the analysis of sediment cores (Brush and Davis, 1984; Cooper and Brush, 1991, 1993; Cooper, 1995a,b). These studies indicated sparse diatom populations in Chesapeake Bay well before European settlement occurred in this region, e.g. prior to 300 years ago. Changes in diatom populations occurred during the 18 and 19th centuries, which were periods of expanded deforestation of the surrounding region, and increased sedimentation occurring in the Bay. Evidence of increased pollution and an increase in diatom abundance is reported taking place in the 20th century by

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Cooper and Brush (Cooper and Brush, 1991). Their results emphasize the transition in diatom composition over the past 2000 years. The major pattern is the increased presence of a plankton flora (e.g. centrales taxa) over benthic species that consisted of mainly pennate diatoms. This was accompanied by decreased diatom diversity and an increase in the centrales : pennales ratio, with centric species becoming more dominant. They note this ratio was 1:3 prior to European settlement and 5:2 in the more recent sediment analysis. Cooper and Brush (Cooper and Brush, 1991) associated this change to increased eutrophication and stress in the benthic community. Their species diversity comparisons (Shannon's H′) show a decrease from 3.8 to 2.3 and 2.5 from two of their cores over this same time period. Since the 18th century, there has been a general relative decline in what were then the more common species. These include *Delphinus surirella*, *Opephora olsenii*, *Cyclotella striata*, *Grammatophora macilentah*, *Navicula abunda*, *Paralia sulcata* and several *Achnanthes* spp. In contrast, the most abundant taxon increasing in abundance throughout this period was *Cyclotella choctawhatcheeana*, with this pattern continuing to the present day. Other taxa showing a similar pattern include *Thalassionema nitzschioides*, *Thalassiosira lineata*, *Thalassiosira proschkinae* and *Neodelphineis pelagica*. Not common in their core samples were many of those diatom genera common today that are lightly silicified (e.g. *Rhizosolenia*, *Leptocylindrus*, *Cerataulina*, *Chaetoceros*). Brush and Davis (Brush and Davis, 1984) associated these floristic changes with increased eutrophic status and turbidity plus an increased frequency of anoxic events in the deeper Bay channels. They also noted a decline in diatom abundance occurring in more recent sediment that they associate with increased phosphorus loading and a possible shift favoring cyanobacteria development.

The first modern era study of Chesapeake Bay phytoplankton water samples was by Wolfe *et al.* (Wolfe *et al.*, 1926, and included seasonal collections from cruises in the Bay between 1916 and 1922. Many of their originally listed taxa have been reclassified (e.g. the more recent nomenclature changes are in parentheses). They reported the dominant species among 99 taxa were *Skeletonema costatum*, *Cerataulina bergonii* (*Cerataulina pelagica*), *Rhizosolenia fragilissima* (*Dactyliosolen fragilissimus*), *Rhizosolenia stolterfothii* (*Guinardia striata*), several *Chaetoceros* spp. and the dinoflagellate *Prorocentrum micans*. Cowles (Cowles, 1930) re-examined these samples in greater detail reporting population maxima during spring and autumn that were dominated by diatoms, with their highest surface abundance from an eastern Bay area at 55.8×10^4 cells L^{-1} in April 1916, and 41.8×10^4 cells L^{-1} in December 1920. In 1920, maximum surface diatom concentrations from upper Bay locations were 76.9 and 59.3×10^4 cells L^{-1}, respectively for March and May. The highest diatom concentrations recorded in 1920 came from two (near) bottom collections in March that were 105.5 and 156.3×10^4 cells L^{-1}. In contrast, the summer (July, August 1920) diatom abundance along the western Bay was $<1.5 \times 10^4$ cells L^{-1}. The most abundant diatom was *S. costatum*. Common pennate diatoms included *Raphoneis amphiceros*, *Nitzschia sigma*, *Pleurosigma balticum*, with common centric diatoms represented by *C. bergonii*, *Actinoptychus undulatus*, *Actinoptychus splendens*, *Leptocylindrus danicus*, *Thalassiothrix nitzschioides* (*T. nitzschioides*) and *Chaetoceros teres*. Oceanic forms included *Chaetoceros decipiens* and *Rhizosolenia alata* (*Proboscia alata*). Common dinoflagellates were *Ceratium furca*, *P. micans* and *Noctiluca miliaris*.

Morse (Morse, 1947) identified in a 2-year study of a tidal river in the northern Bay region 141 taxa dominated by diatoms (91) and dinoflagellates (41). The dinoflagellates included *C. furca*, *P. micans* and *Peridinium triqueta*. The dominant diatoms were *S. costatum*, *Asterionella japonica*, *C. bergonii*, *Schroederella delicatula*, *Nitzschia seriata*, and *T. nitzschioides*. Only three cyanobacteria, two chlorophytes and a single euglenophyte were included. Several other composition studies occurred in later years (Griffith, 1961; Patten *et al.*, 1963; Marshall, 1980, 1988, 1991, 1994; Marshall and Lacouture, 1986; Marshall and Alden, 1990a,b, 1993; Marshall and Burchardt, 1998, 2003, 2004a,b). These greatly expanded the phytoplankton records for the Bay and its tributaries, including representation of other phylogenetic categories. For instance, Marshall (Marshall, 1994) identified 708 phytoplankton taxa from a 7-year data set (1985–1992) of monthly collections in Chesapeake Bay.

These more recent studies indicate Chesapeake Bay phytoplankton is dominated by several diatom assemblages throughout the year, with chlorophytes, cyanobacteria (cyanoprokaryotes), cryptomonads and dinoflagellates having seasonal periods of dominance and development that varies within the different salinity regions of the ecosystem (Marshall and Affronti, 1992; Marshall and Nesius, 1993, 1996; Marshall and Burchardt, 1998, 2004b). These populations are enhanced by species that enter the Chesapeake Bay from both neritic coastal waters and its tributaries. There are also established endemic phytoplankton populations in the various subestuaries and inlets within Chesapeake Bay that contribute to this rich and dynamic flora. The objectives of this presentation are to (i) update the phytoplankton composition in Chesapeake Bay and its tidal tributaries, (ii) identify potential toxic species recorded from these waters and (iii) to make comparisons to earlier records of phytoplankton composition and abundance in Chesapeake Bay.

METHOD

This study is based on the analysis of phytoplankton by the authors during the Virginia and Maryland Chesapeake Bay Phytoplankton Monitoring Program conducted in Chesapeake Bay and its tidal rivers from 1984 to 2004. Monthly water samples were taken at established stations, preserved in Lugol's solution and examined under light microscopy for the composition and abundance of taxa (Marshall and Alden, 1990b; Marshall, 1993). Epifluorescence microscopy, genetic molecular analysis and scanning electron microscopy were also used as further aids in species identification. Previous taxonomic records from other Chesapeake Bay studies by the authors have also been added in this report. Collection sites were located in tidal freshwater (<0.5), oligohaline (0.5–5.0), mesohaline (5.0–18.0) and polyhaline waters (>18.0) (Marshall, 1993). Field and laboratory methods plus data collected during the Chesapeake Bay Phytoplankton Monitoring program are available at http://www. chesapeakebay.net/ data/index.htm. Data records from other collections are contained in the publications cited in this article.

In recent decades, phytoplankton systematics has undergone numerous changes that include the transferring (and renaming) of various taxa to other existing, or new genera, with even broader taxonomic modifications proposed for other taxa. Although the majority of these changes have been accepted by phycologists, the use of the previous nomenclature for many of these taxa continues to appear in the literature. The reader is alerted that many of these changes have been incorporated in the listing of species provided here and that nomenclature changes will likely continue to occur, as well as other species added to this list. A variety of references emphasizing different phytoplankton categories was used for species identification and include those listed by Marshall (Marshall, 1994), plus others (Prescott, 1951; Ettle, 1978; Komárek and Anagnostidis, 1986; Anagnostidis and Komárek, 1988; Hindák, 1988; Krammer and Lange-Bertalot, 1991; Tomas, 1997).

RESULTS

A total of 1454 taxa were identified from the Bay and its associated subestuaries and tidal tributaries (Table I). These include 675 bacillariophyceae, 273 chlorophyceae, 190 dinophyceae, 126 cyanobacteria, 64 euglenophyceae, 39 chrysophyceae, 25 xanthophyceae, 17 coccolithophoridaceae, 18 cryptophyceae, 12 prasinophyceae, 5 raphidophyceae, 5 prymnesiophyceae and 5 dictyochophyceae. The increased representation for many of these categories compared with those reported by Marshall (Marshall, 1994) came from the inclusion of flora from the tidal rivers that contained a greater proportion of chlorophytes, cyanobacteria and euglenophytes than were previously reported in Chesapeake Bay. Increased observations within Chesapeake Bay from a greater sampling base in recent years have also provided the authors additional opportunities to identify phytoplankton taxa in these waters. However, there are many taxa whose taxonomic status have been confusing. For instance, comparable descriptions have been attributed to *Cyclotella caspia*, *C. choctawhatcheeana* and *Cyclotella hakanssoniae*. Håkansson *et al.* (Håkansson *et al.*, 1993) state that *C. choctawhatcheeana* and *C. caspia* are distinct species and that *C. hakanssoniae* is a synonym of *C. choctawhatcheeana*.

In comparison with the previously mentioned sediment core records by Cooper and Brush (Cooper and Brush, 1991, 1993; Cooper, 1995a), our data indicated the trend for increased abundance of centric diatoms has continued (Marshall *et al.*, 2003) and specifically the dominance of *Cyclotella* spp. A dominant plankton flora composed of centric species represented one of the most abundant taxonomic groups. Unfortunately, the previous sediment core analysis could only address diatom composition and not other flora. In addition, many of the early phytoplankton studies used methods (e.g. net collections) that limited the populations that were collected, so comparisons regarding these floral results to present representations were very limited. However, since the Bay collections of 1916–1922 (Wolfe *et al.*, 1926; Cowles, 1930), *S. costatum* has remained one of the dominant (e.g. in abundance) diatoms in the Bay. In fact, many of the dominant taxa reported during the period 1916–1922 are taxa presently dominant within the system. Several of the more common dinoflagellates over the past 8 decades have been *C. furca* and *P. micans* (with possibly a smaller taxon described at that time being *Prorocentrum minimum*. There remains a diverse assemblage of pennate diatoms that are predominantly benthic species. In comparison with the surface cell concentrations recorded by Cowles (Cowles, 1930), the abundance of diatoms during spring and summer periods in Chesapeake Bay have increased dramatically compared to Marshall and Alden (Marshall and Alden, 1993) and present records. Spring surface diatom concentrations often exceed 10^6 cells L^{-1} compared with the highest counts of 55.8–76.9 $\times$ 10^4 cells L^{-1} noted by Cowles (Cowles, 1930). In addition, more recent diatom concentrations during summer also exceed those reported by Cowles (Cowles, 1930), e.g. 10^6 cells L^{-1} compared with 10^4 cells L^{-1}, as reported by Marshall and Alden (Marshall and Alden, 1993). Similar differences

Table I: Phytoplankton taxa recorded in Chesapeake Bay, its tidal rivers and subestuaries

Bacillariophyceae

Centrales

Actinocyclus normanii f. *normanii* (Gregory) Hustedt

Actinoptychus senarius (Ehrenberg) Ehrenberg, *Actinoptychus splendens* (Shadbolt) Ralfs, *Actinoptychus vulgaris* Schumann, *Actinoptychus undulatus* (J. W. Bailey) Ralfs

Asterolampra marylandica Ehrenberg

Asteromphalus sp., *Asteromphalus flabellatus* (Brébisson) Greville, *Asteromphalus heptactis* (Brébisson) Ralfs, *Asteromphalus roperianus* (Greville) Ralfs

Aulacodiscus sp.

Aulacoseira sp., *Aulacoseira distans* (Ehrenberg) Simonsen, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Aulacoseira granulata* var. *angustissima* (O. Müller) Simonsen, *Aulacoseira herzogii* (Lemmermann) Simonsen, *Aulacoseira islandica* (Müller) Simonsen, *Aulacoseira italica* (Ehrenberg) Simonsen, *Aulacoseira italica* var. *tenuissima* (Grunow) Simonsen

Auliscus sculptus (W. Smith) Ralfs

Attheya decora West

Azpeitia nodulifiera (A. Schmidt) Fryxell and Sims

Bacteriastrum sp., *Bacteriastrum comosum* Pavillard, *Bacteriastrum delicatulum* P. T. Cleve, *Bacteriastrum elongatum* P. T. Cleve, *Bacteriastrum furcatum* Shadbolt, *Bacteriastrum hyalinum* Lauder, *Bacteriastrum hyalinum* var. *princeps* (Castracane) Ikari

Bellerochea horologicalis Von Stosch, *Bellerochea malleus* (Brightwell) Van Heurck

Campylosira sp., *Campylosira cymbelliformis* (Schmidt) Grunow

Cerataulina pelagica (Cleve) Hendey

Cerataulus radiatus (Roper) Ross

Chaetoceros sp., *Chaetoceros affinis* Lauder, *Chaetoceros affinis* var. *willei* (Gran) Hustedt, *Chaetoceros atlanticus* P. T. Cleve, *Chaetoceros borealis* Bailey, *Chaetoceros brevis* Schütt, *Chaetoceros coarctatus* Lauder, *Chaetoceros compressus* Lauder, *Chaetoceros concavicornis* Mangin, *Chaetoceros constrictus* Gran, *Chaetoceros convolutus* Castracane, *Chaetoceros crinitus* Schütt, *Chaetoceros costatus* Pavillard, *Chaetoceros curvisetus* P. T. Cleve, *Chaetoceros danicus* P. T. Cleve, *Chaetoceros debilis* P. T. Cleve, *Chaetoceros decipiens* P. T. Cleve, *Chaetoceros densus* P. T. Cleve, *Chaetoceros diadema* (Ehrenberg) Gran, *Chaetoceros didymus* Ehrenberg, *Chaetoceros didymus* var. *protuberans* (Lauder) Gran and Yendo, *Chaetoceros difficilis* P. T. Cleve, *Chaetoceros diversus* P. T. Cleve, *Chaetoceros fragilis* Meunier, *Chaetoceros gracilis* Schütt, *Chaetoceros laciniosus* Schütt, *Chaetoceros lorenzianus* Grunow, *Chaetoceros messanensis* Castracane, *Chaetoceros muelleri* Lemmermann, *Chaetoceros neapolitanus* Schröder, *Chaetoceros neogracilis* Van Laningham, *Chaetoceros pelagicus* P. T. Cleve, *Chaetoceros pendulus* Karsten, *Chaetoceros peruvianus* Brightwell, *Chaetoceros pseudocurvisetus* Mangin, *Chaetoceros radians* Schütt, *Chaetoceros rostratus* Lauder, *Chaetoceros similis* P. T. Cleve, *Chaetoceros simplex* Ostenfeld, *Chaetoceros socialis* Lauder, *Chaetoceros subtilis* P. T. Cleve, *Chaetoceros tenuissimus* Meunier, *Chaetoceros teres* P. T. Cleve, *Chaetoceros tetrastichon* P. T. Cleve, *Chaetoceros tortissimus* Gran, *Chaetoceros wighamii* Brightwell

Climacodium sp., *Climacodium biconcavum* P. T. Cleve, *Climacodium frauenfeldianum* Grunow

Corethron sp., *Corethron criophilum* Castracane, *Corethron hystrix* Hensen, *Corethron valdiviae* Karsten

Coscinodiscus sp., *Coscinodiscus apiculiferus* Rattray, *Coscinodiscus argus* Ehrenberg, *Coscinodiscus asteromphalus* Ehrenberg, *Coscinodiscus centralis* Ehrenberg, *Coscinodiscus cinctus* Kützing, *Coscinodiscus concinnus* W. Smith, *Coscinodiscus gigas* Ehrenberg, *Coscinodiscus gigas* var. *praetexta* (Janisch) Hustedt, *Coscinodiscus granii* Gough, *Coscinodiscus granulosus* Grunow, *Coscinodiscus kuetzingii* A. Schmidt, *Coscinodiscus lacustris* Grunow, *Coscinodiscus marginatus* Ehrenberg, *Coscinodiscus nitidus* Gregory, *Coscinodiscus nobilis* Grunow, *Coscinodiscus obscurus* Schmidt, *Coscinodiscus oculus-iridis* Ehrenberg, *Coscinodiscus perforatus* Ehrenberg, *Coscinodiscus radiatus* Ehrenberg, *Coscinodiscus rothii* (Ehrenberg) Grunow, *Coscinodiscus rothii* var. *subsalsa* (Juhlin-Dannfelt) Hustedt, *Coscinodiscus rotula* Grunow, *Coscinodiscus subbulliens* Jørgenson, *Coscinodiscus sublineatus* (Grunow) Rattray, *Coscinodiscus wailesii* Gran and Angst

Cyclostephanos sp., *Cyclostephanos dubius* (Fricke) Round

Cyclotella sp., *Cyclotella atomus* Hustedt, *Cyclotella bodanica* Grunow, *Cyclotella caspia* Grunow, *Cyclotella chaetoceros* Lemmermann, *Cyclotella choctawhatcheeana* Prasad, *Cyclotella cryptica* Reimann, *Cyclotella commensis* Grunow, *Cyclotella comta* (Ehrenberg) Kützing, *Cyclotella glomerata* Bachmann, *Cyclotella meneghiniana* Kützing, *Cyclotella stelligera* Cleve and Grunow, *Cyclotella striata* (Kützing) Grunow, *Cyclotella stylorum* Brightwell

Dactyliosolen antarcticus Castracane, *Dactyliosolen fragilissimus* Bergon (Hasle)

Detonula confervacea (Cleve) Gran, *Detonula pumila* (Castracane) Schütt

Ditylum brightwellii (West) Grunow

(continued)

Table I: continued

Eucampia cornuta (Cleve) Grunow, *Eucampia zodiacus* Ehrenberg

Guinardia cylindrus (P. T. Cleve) Hasle, *Guinardia delicatula* (P. T. Cleve) Hasle, *Guinardia flaccida* (Castracane) Peragallo, *Guinardia striata* (Stolterfoth) Hasle

Helicotheca tamesis (Shrubsole) Ricard

Hemiaulus sp., *Hemiaulus hauckii* Grunow, *Hemiaulus indicus* Karsten, *Hemiaulus membranaceus* Cleve, *Hemiaulus sinensis* Greville

Hemidiscus cuneiformis Wallich

Lauderia annulata P. T. Cleve

Leptocylindrus danicus P. T. Cleve, *Leptocylindrus mediterraneus* (Peragallo) Hasle, *Leptocylindrus minimus* Gran

Lithodesmium sp., *Lithodesmium undulatum* Ehrenberg

Melosira sp., *Melosira ambigua* (Grunow) O. Müller, *Melosira arenaria* Moore, *Melosira dickiei* (Thwaites) Kützing, *Melosira dubia* Kützing, *Melosira hummii* Hustedt, *Melosira lineata* (Dillwyn) Agardh, *Melosira islandica* f. *curvata* (Ehrenberg) Müller, *Melosira islandica* var. *helvetica* Müller, *Melosira moniliformis* (Müller) Agardh, *Melosira nummuloides* (Dillwyn) Agardh, *Melosira varians* Agardh

Odontella sp., *Odontella alternans* (Bailey) Van Heurck, *Odontella aurita* (Lyngbye) Agardh, *Odontella aurita* var. *obtusa* (Kützing) Hustedt, *Odontella granulata* (Roper) R. Ross, *Odontella longicruris* Greville, *Odontella mobiliensis* (Bailey) Grunow, *Odontella pulchella* Gray, *Odontella regia* (Schultz) Ostenfeld, *Odontella reticulata* (Ehrenberg) Roper, *Odontella obtusa* Kützing, *Odontella rhombus* (Ehrenberg) Kützing, *Odontella rhombus* f. *trigona* (Cleve) R. Ross, *Odontella sinensis* (Greville) Gronow, *Odontella tridens* (Ehrenberg) Ehrenberg

Paralia sulcata (Ehrenberg) P. T. Cleve

Plagiogramma sp., *Plagiogramma interruptum* (Gregory) Ralfs, *Plagiogramma staurophorum* (Gregory) Heiberg

Plagiogrammopsis vanheurckii Grunow

Planktoniella sol (Wallich) Schutt

Podosira sp., *Podosira stelligera* (J. W. Bailey) A. Mann

Porosira gracialis (Granow) Jørgensen

Proboscia alata (Brightwell) Sundström, *Proboscia alata* f. *curvirostris* Gran, *Proboscia alata* f. *gracillima* (Cleve) Grunow, *Proboscia alata* f. *indica* (Peragallo) Gran, *Proboscia inermis* (Castracane) Jordon and Ligowski

Pseudosolenia calcar-avis (Schultze) Sunderstrom

Rhizosolenia sp., *Rhizosolenia acuminata* (Peragallo) Peragallo, *Rhizosolenia bergonii* Peragallo, *Rhizosolenia castracanei* Peragallo, *Rhizosolenia eriensis* H. L. Smith, *Rhizosolenia formosa* Peragallo, *Rhizosolenia hebetata* Bailey, *Rhizosolenia hebetata* f. *semispina* (Hensen) Gran, *Rhizosolenia imbricata* Brightwell, *Rhizosolenia rhombus* Karsten, *Rhizosolenia robusta* Norman, *Rhizosolenia setigera* Brightwell, *Rhizosolenia styliformis* Brightwell, *Rhizosolenia temperei* Peragallo

Skeletonema costatum (Greville) P. T. Cleve, *Skeletonema potamos* (Weber) Hasle

Stellarima microtrias (Ehrenberg) Hasle and Sims

Stephanodiscus astraea (Ehrenberg) Grunow, *Stephanodiscus hantzschii* Grunow, *Stephanodiscus subsalsus* (Cleve) Hustedt

Stephanopyxis sp., *Stephanopyxis nipponica* Gran and Yendo, *Stephanopyxis palmeriana* (Greville) Grunow, *Stephanopyxis turris* (Greville and Arnott) Ralfs

Thalassionema sp., *Thalassionema nitzschioides* (Grunow) Grunow and Hustedt

Thalassiosira sp., *Thalassiosira aestivalis* Gran and Angst, *Thalassiosira anguste-lineata* (Schmidt) Fryxell and Hasle, *Thalassiosira antarctica* Comber, *Thalassiosira baltica* (Grunow) Ostenfeld, *Thalassiosira bioculata* (Grunow) Ostenfeld, *Thalassiosira decipiens* (Grunow) Jørgensen, *Thalassiosira delicatula* Ostenfeld, *Thalassiosira eccentrica* (Ehrenberg) P. T. Cleve, *Thalassiosira gravida* P. T. Cleve, *Thalassiosira guillardii* Hasle, *Thalassiosira hyalina* (Grunow) Gran, *Thalassiosira lacustris* (Grunow) Hasle and Fryxell, *Thalassiosira leptopus* (Grunow) Fryxell and Hasle, *Thalassiosira lineata* Jousé, *Thalassiosira nordenskioeldii* P. T. Cleve, *Thalassiosira oestrupii* var. *venrickae* Fryxel and Hasle, *Thalassiosira proschkinae* Makarova, *Thalassiosira pseudonana* (Hustedt) Hasle and Heimdal, *Thalassiosira rotula* Meunier, *Thalassiosira subtilis* (Ostenfeld) Gran, *Thalassiosira tenera* Proschkina-Laurenko

Triceratium sp., *Triceratium acutum* Ehrenberg, *Triceratium favus* Ehrenberg, *Triceratium formosum* f. *pentagonale* (Schmidt) Hustedt, *Triceratium reticulum* Ehrenberg

Trinacria regina Heiberg

Pennales

Achnanthes sp., *Achnanthes clevei* Grunow, *Achnanthes delicatula* (Kützing) C. A. Grunow, *Achnanthes danica* (Flögel) Grunow, *Achnanthes fimbriata* (Grunow) Ross, *Achnanthes lemmermannii* Hustedt, *Achnanthes longipes* Agardh, *Achnanthes onegensis* (Wislouch and Kolbe) Van Landingham, *Achnanthes subsalsoides* Hustedt, *Achnanthes taeniata* Grunow

(continued)

Table I: continued

Amphiprora sp., *Amphiprora alata* (Ehrenberg) Kützing, *Amphiprora cholnokyi* Van Lan., *Amphiprora conspicua* Greville, *Amphiprora costata* (W. Smith) Hustedt, *Amphiprora ornata* J. W. Bailey, *Amphiprora paludosa* W. Smith, *Amphiprora gigantea* var. *sulcata* (O'Meara) Cleve
Amphora sp., *Amphora cuta* Gregory, *Amphora angusta* Gregory, *Amphora arenaria* Donkin, *Amphora binodis* Gregory, *Amphora coffeaeformis* (Agardh) Kützing, *Amphora commutata* Grunow, *Amphora costata* W. Smith, *Amphora crassa* Gregory, *Amphora cuneata* Cleve, *Amphora egregia* var. *interrupta* Peragallo and Peragallo, *Amphora exigua* Gregory, *Amphora gigantea* Grunow, *Amphora grevilleana* var. *contracta* Cleve, *Amphora laevis* Gregory, *Amphora lineolata* Ehrenberg, *Amphora luciae* Cholnoky, *Amphora marina* (W. Smith) Van Heurck, *Amphora obtusa* Gregory, *Amphora ostrearia* Brébisson, *Amphora ovalis* (Kützing) Kützing, *Amphora peragalli* Cleve, *Amphora proteoides* Hustedt, *Amphora proteus* Gregory, *Amphora robusta* Gegory, *Amphora rhombica* Kitton, *Amphora sabyii* Salah, *Amphora spectabilis* Gregory, *Amphora szaboi* Pantocsek, *Amphora terroris* Ehrenberg, *Amphora turgida* Gregory, *Amphora veneta* Kützing
Asterionella formosa Hassall, *Asterionella notata* (Grunow) Grunow
Asterionellopsis glacialis (Castracane) Round, *Asterionellopsis kariana* (Grunow) Round
Auricula insecta (Grunow) Schmidt
Bacillaria paxillifer (O. F. Müller) Hendey
Berkeleya rutilans (Trentepohl) Grunow
Bleakeleya notata (Grunow) Round
Caloneis sp., *Caloneis fusioides* (Grunow) Heiden and Kolbe, *Caloneis lamella* Zakrzewski, *Caloneis lepidula* (Grunow) P. T. Cleve, *Caloneis silicula* (Ehrenberg) P. T. Cleve, *Caloneis staurophora* (Grunow) P. T. Cleve, *Caloneis subsalina* (Donkin) Hendey, *Caloneis trinodis* Schultze, *Caloneis wardii* P. T. Cleve, *Caloneis westii* (W. Smith) Hendey
Campylodiscus echeneis Ehrenberg, *Campylodiscus limbatus* Brébisson
Catenula adhaerens (Mereschkowsky) Mereschkowsky
Cocconeis sp., *Cocconeis clandestina* Schmidt, *Cocconeis costata* Gregory, *Cocconeis distans* Gregory, *Cocconeis disculus* (Schumann) P. T. Cleve, *Cocconeis flumiatilis* Wallace, *Cocconeis molesta* var. *crucifera* Grunow, *Cocconeis pediculus* Ehrenberg, *Cocconeis pinnata* Gregory, *Cocconeis placentula* Ehrenberg, *Cocconeis scutellum* Ehrenberg, *Cocconeis scutellum* var. *ornata* Grunow
Cylindrotheca closterium (Ehrenberg) Reimann and Lewin
Cymatopleura elliptica (Brébisson) W. Smith, *Cymatopleura solea* (Brébisson) W. Smith
Cymatosira belgica Grunow, *Cymatosira lorenziana* Grunow
Cymbella sp., *Cymbella affinis* Kützing, *Cymbella excisa* Kützing, *Cymbella helvetica* Kützing, *Cymbella tumida* (Brébisson) VanHeurck, *Cymbella turgidula* Grunow, *Cymbella ventricosa* Kützing
Delphineis surirella (Ehrenberg) Grunow
Diatoma sp., *Diatoma anceps* (Ehrenberg) Kirchner, *Diatoma elongatum* (Lyngbye) Agardh, *Diatoma hyemale* (Roth) Heiberg, *Diatoma tenue* (Lyngbye) Agardh, *Diatoma vulgaris* Bory
Dimerogramma sp., *Dimerogramma minor* (Gregory) Ralfs
Diploneis sp., *Diploneis beyrichiana* (Schmidt) Amosse, *Diploneis bombus* (Ehrenberg) Ehrenberg, *Diploneis constricta* (Grunow) P. T. Cleve, *Diploneis crabro* Ehrenberg, *Diploneis crabro* var. *pandura* (Brébisson) P. T. Cleve, *Diploneis elliptica* (Kützing) P. T. Cleve, *Diploneis gruendleri* (Schmidt) P. T. Cleve, *Diploneis interrupta* (Kützing) P. T. Cleve, *Diploneis litoralis* (Donkin) Cleve, *Diploneis obliqua* (Brun) Hustedt, *Diploneis ovalis* (Hilse) P. T. Cleve, *Diploneis smithii* (Brébisson) P. T. Cleve, *Diploneis subcincta* (Schmidt) P. T. Cleve, *Diploneis suborbicularis* (Gregory) P. T. Cleve
Epithemia sp., *Epithemia argus* (Ehrenberg) Kützing, *Epithemia sorex* Kützing, *Epithemia turgida* (Ehrenberg) Kützing
Eunotia sp., *Eunotia bidentula* W. Smith, *Eunotia lunaris* (Ehrenberg) Grunow, *Eunotia microcephala* Krasske, *Eunotia pectinalis* (O. F. Müller) Rabenhorst, *Eunotia praerupta* Ehrenberg, *Eunotia serra* var. *diadema* (Ehrenberg) Patrick
Fragilaria sp., *Fragilaria capucina* Desmazieres, *Fragilaria construens* (Ehrenberg) Grunow, *Fragilaria crotonensis* Kitton, *Fragilaria hyalina* (Kützing) Grunow, *Fragilaria intermedia* (Grunow) Grunow, *Fragilaria leptostauron* var. *martyi* (Heribaud) Lange-Bertalot, *Fragilaria oceanica* Cleve, *Fragilaria pinnata* Ehrenberg, *Fragilaria schulzii* Brockmann, *Fragilaria striatula* Lyngbye, *Fragilaria virescens* Ralfs
Fragilariopsis cylindrus (Grunow and Cleve) Hasle, *Fragilariopsis oceanica* (Cleve) Hasle
Frustulia sp., *Frustulia rhomboides* (Ehrenberg) DeToni
Glyphodesmis distans (Gregory) Grunow
Gomphonema sp., *Gomphonema acuminatum* Ehrenberg, *Gomphonema augur* Ehrenberg, *Gomphonema constrictum* Ehrenberg, *Gomphonema exiguum* Kützing, *Gomphonema geminatum* (Lyngbye) Agardh, *Gomphonema olivaceum* (Lyngbye) Kützing, *Gomphonema sphaerophorum* Ehrenberg
Grammatophora sp., *Grammatophora angulosa* Ehrenberg, *Grammatophora marina* (Lyngbye) Kützing, *Grammatophora serpentina* Ehrenberg

(continued)

Table I: continued

Gyrosigma sp., *Gyrosigma acuminatum* (Kützing) Rabenhorst, *Gyrosigma balticum* (Ehrenberg) Rabenhorst, *Gyrosigma balticum* var. *silimis* (Grunow) Cleve, *Gyrosigma distortum* (W. Smith) Cleve, *Gyrosigma distortum* var. *parkeri* Harrisson, *Gyrosigma fasciola* (Ehrenberg) Griffith and Henfrey, *Gyrosigma hippocampus* (Ehrenberg) Hassall, *Gyrosigma macrum* (W. Smith) Griffth and Henfrey, *Gyrosigma scalproides* (Rabenhorst) P. T. Cleve, *Gyrosigma spenceri* (Quekett) Griffith and Henfrey, *Gyrosigma spenceri* var. *nodiferum* (Grunow) P. T. Cleve, *Gyrosigma wansbeckii* (Donkin) P. T. Cleve

Hantzchia sp., *Hantzchia amphioxys* (Ehrenberg) Grunow, *Hantzchia marina* (Donkin) Grunow, *Hantzchia spectabilis* (Ehrenberg) Hustedt

Licmophora sp., *Licmophora abbreviata* Agardh, *Licmophora flabellata* (Carmichael) Agardh, *Licmophora gracilis* (Ehrenberg) Grunow, *Licmophora inflata* Mereschkowsky, *Licmophora paradoxa* (Lyngbye) Agardh, *Licmophora paradoxa* var. *tincta* (Agardh) Hustedt, *Licmophora tincta* Grunow

Lioloma delicatulum Cupp

Mastogloia sp., *Mastogloia apiculata* W. Smith, *Mastogloia braunii* Grunow, *Mastogloia cocconeiformis* Grunow, *Mastogloia exigua* Lewis, *Mastogloia gibbosa* Brun, *Mastogloia pumila* (Cleve and Möller) Cleve, *Mastogloia rostrata* (Wallich) Hustedt, *Mastogloia smithii* Thwaites

Membraneis challengeri Grunow

Meridion circulare (Greville) Agardh

Navicula sp., *Navicula abrupta* (Gregory) Donkin, *Navicula amphipleuroides* Hustedt, *Navicula annulata* Grunow, *Navicula apiculata* Brébisson, *Navicula arenaria* Donkin, *Navicula arvensis* Hustedt, *Navicula atomus* (Kützing) Grunow, *Navicula cancellata* Donkin, *Navicula caterva* Hohn and Hellerman, *Navicula cincta* (Ehrenberg) Ralfs, *Navicula clavata* Gregory, *Navicula cryptocephala* Kützing, *Navicula cruciculoides* Brockmann, *Navicula cryptocephala* Kützing, *Navicula cuspidata* Kützing, *Navicula cuspidata* var. *ambigua* (Ehrenberg) Cleve, *Navicula delawarensis* Grunow, *Navicula digitoradiata* (Gregory) Ralfs, *Navicula directa* (W. Smith) Ralfs, *Navicula distans* (W. Smith) Ralfs, *Navicula eidrigeana* Carter, *Navicula escorialis* Simonsen, *Navicula forcipata* Greville, *Navicula gastrum* (Ehrenberg) Kützing, *Navicula gracilis* Ehrenberg, *Navicula gracilis* var. *neglecta* (Thwaites) Grunow, *Navicula granulata* J. W. Bailey, *Navicula gregaria* Donkin, *Navicula halophila* (Grunow) Cleve, *Navicula hanseni* Möller, *Navicula hasta* Pantocsek, *Navicula hennedyii* W. Smith, *Navicula humerosa* Brébisson, *Navicula laevissima* Kützing, *Navicula longa* (Gregory) Ralfs, *Navicula lundstroemii* Cleve, *Navicula lyra* Ehrenberg, *Navicula maculosa* Donkin, *Navicula marina* Ralfs, *Navicula inserata* Hustedt, *Navicula irrorata* Greville, *Navicula maculata* (Bailey) Edwards, *Navicula membranacea* Cleve, *Navicula northumbrica* Donkin, *Navicula opima* Grunow, *Navicula paleralis* (Brébison) W. Smith, *Navicula palpebralis* Brébisson, *Navicula peregrina* (Ehrenberg) Kützing, *Navicula phyllepa* Kützing, *Navicula placenta* Ehrenberg, *Navicula placentula* (Ehrenberg) Kützing, *Navicula praetexta* Ehrenberg, *Navicula producta* W. Smith, *Navicula pusilla* W. Smith, *Navicula radiosa* Kützing, *Navicula rhombica* Gregory, *Navicula rhynchocephala* Kützing, *Navicula salinarum* Grunow, *Navicula septentrionalis* (Grunow) Gran, *Navicula sovereignae* Hustedt, *Navicula spectabilis* Gregory, *Navicula transitans* var. *asymmetrica* (Cleve) Cleve, *Navicula tripunctata* (O. F. Müller) Bory, *Navicula tuscula* Ehrenberg, *Navicula viridula* (Kützing) Ehrenberg

Neidium affine (Ehrenberg) Pfitzer

Neodelphineis pelagica Takano

Nitzschia sp., *Nitzschia acuminata* (W. Smith) Grunow, *Nitzschia actinastroides* (Lemmermann) Van Goor, *Nitzschia acicularis* W. Smith, *Nitzschia amphibia* Grunow, *Nitzschia angularis* W. Smith, *Nitzschia angularis* var. *affinis* Grunow, *Nitzschia angustata* Grunow, *Nitzschia apiculata* (Gregory) Grunow, *Nitzschia bergii* A. Cleve-Euler, *Nitzschia bilobata* W. Smith, *Nitzschia bilobata* var. *minor* Grunow, *Nitzschia calida* Grunow, *Nitzschia clausii* Hantzsch, *Nitzschia compressa* (J. W. Bailey) Boyer, *Nitzschia constricta* (Kützing) Ralfs, *Nitzschia denticula* Grunow, *Nitzschia dissipata* (Kützing) Grunow, *Nitzschia distans* Gregory, *Nitzschia fasciculata* (Grunow) Grunow, *Nitzschia filiformis* (W. Smith) Hustedt, *Nitzschia frustulum* (Kützing)Grunow, *Nitzschia gracillima* Heiden and Kolbe, *Nitzschia gracilis* Hantzsch, *Nitzschia granulata* Grunow, *Nitzschia holsatica* Hustedt, *Nitzschia hybrida* Grunow, *Nitzschia insignis* Gregory, *Nitzschia lanceolata* W. Smith, *Nitzschia liebethruthii* Rabenhorst, *Nitzschia linearis* (C. Agardh) W. Smith, *Nitzschia longissima* (Brébisson) Ralfs, *Nitzschia lorenziana* Grunow, *Nitzschia lorenziana* var. *subtilis* Grunow, *Nitzschia lorenziana* var. *densistriata* Grunow, *Nitzschia lorenziana* var. *incerta* Grunow, *Nitzschia microcephala* Grunow, *Nitzschia navicularis* (Brébisson) Grunow, *Nitzschia obtusa* W. Smith, *Nitzschia obtusa* var. *scalpelliformis* Grunow, *Nitzschia pacifica* Cupp, *Nitzschia palea* (Kützing) W. Smith, *Nitzschia paleacea* (Grunow) Grunow, *Nitzschia panduriformis* Gregory, *Nitzschia parvula* W. Smith, *Nitzschia pellucida* Grunow, *Nitzschia plana* W. Smith, *Nitzschia proxima* Hustedt, *Nitzschia punctata* (W. Smith) Grunow, *Nitzschia pusilla* (Kützing) Grunow, *Nitzschia recta* Hantzsch, *Nitzschia sigma* (Kützing) W. Smith, *Nitzschia sigma* var. *intercedens* Grunow, *Nitzschia sigma* var. *rigida* (Kützing) Grunow, *Nitzschia sigmoidea* (Nitzsch) W. Smith, *Nitzschia socialis* Gregory, *Nitzschia sociabilis* Hustedt, *Nitzschia spathulata* Brébisson, *Nitzschia spectabilis* (Ehrenberg) Ralfs, *Nitzschia thermalis* (Ehrenberg) Auerswals, *Nitzschia trybionella* Hantzsch, *Nitzschia trybionella* var. *levidensis* (W. Smith) Grunow, *Nitzschia valida* Grunow, *Nitzschia vermicularis* (Kützing) Hantzsch, *Nitzschia vitrea* Norman

Opephora mutabilis (Grunow) Sabbe and Vyverman

Pinnularia sp., *Pinnularia gibba* Ehrenberg, *Pinnularia lata* (Brebisson) W. Smith, *Pinnularia legumen* Ehrenberg, *Pinnularia major* (Kützing) Rabenhorst, *Pinnularia nobilis* (Ehren.) Ehrenberg, *Pinnularia notabilis* Kramer, *Pinnularia rectangulata* (Gregory) Rabenhorst, *Pinnularia trevelyana* (Donkin) Rabenhorst, *Pinnularia viridis* (Nitzsch) Ehrenberg

(continued)

Table I: continued

Pleurosigma sp., *Pleurosigma acutum* Norman, *Pleurosigma aestuarii* (Brébisson) W. Smith, *Pleurosigma angulatum* (Quekett) W. Smith, *Pleurosigma angulatum* var. *strigosa* (W. Smith) Van Heurck, *Pleurosigma delicatulum* W. Smith, *Pleurosigma directum* Grunow, *Pleurosigma elongatum* W. Smith, *Pleurosigma formosum* W. Smith, *Pleurosigma hamuliferum* Brun, *Pleurosigma naviculaceum* Brébisson, *Pleurosigma nicobaricum* (Grunow) Grunow, *Pleurosigma normanii* Ralfs, *Pleurosigma obscurum* W. Smith, *Pleurosigma rigidum* W. Smith, *Pleurosigma salinarum* Grun, *Pleurosigma strigosum* W. Smith

Pseudo-nitzschia cuspidata (Hasle) Hasle, *Pseudo-nitzschia multiseries* (Hasle) Hasle, *Pseudo-nitzschia pseudodelicatissima* (Hasle) Hasle, *Pseudo-nitzschia pungens* (Grunow) Hasle, *Pseudo-nitzschia seriata* (Cleve) Peragallo, *Pseudo-nitzschia subpacifica* (Hasle) Hasle

Rhabdonema sp., *Rhabdonema arcuatum* (Lyngbye) Kützing, *Rhabdonema minutum* Kützing

Rhaphoneis sp., *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg

Rhoicosphenia abbreviata (Agardh) Lange-Bertalot

Rhopalodia sp., *Rhopalodia gibba* (Ehrenberg) O. Müller, *Rhopalodia gibberula* (Ehrenberg) O. Möller, *Rhopalodia operculata* (C. Agardh) Håkansson

Scoliotropis latestriata (Brébisson) Cleve

Stauroneis sp., *Stauroneis amphioxys* Gregory, *Stauroneis anceps* var. *hyalina* Peragallo, *Stauroneis membranacea* (Cleve) F. W. Mills, *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg, *Stauroneis salina* W. Smith

Stenopterobia anceps (Lewis) Brébisson

Striatella sp., *Striatella interrupta* (Ehrenberg) Heiberg, *Striatella unipunctata* (Lyngbye) Agardh

Surirella sp., *Surirella capronii* Brébisson, *Surirella cruciata* Schmidt, *Surirella elegans* Ehrenberg, *Surirella fatuosa* var. *recedens* (Schmidt) Cleve, *Surirella gemma* Bailey, *Surirella ovalis* Brébisson, *Surirella ovata* Kützing, *Surirella pandura* var. *contracta* Peragallo and Peragallo, *Surirella patella* Ehrenberg, *Surirella robusta* Ehrenberg, *Surirella robusta* var. *splendida* (Ehrenberg) Van Heurck, *Surirella spiralis* Kützing, *Surirella striatula* Turpin, *Surirella tenera* Gregory

Synedra sp., *Synedra acus* Kützing, *Synedra closterioides* Grunow, *Synedra crystallina* (Agardh) Kützing, *Synedra fabulata* (Agardh) Kützing, *Synedra fulgens* (Greville) W. Smith, *Synedra gaillonii* (Bory) Ehrenberg, *Synedra pulchella* (Ralfs) Kützing, *Synedra provincialis* Grunow, *Synedra robusta* Ralfs, *Synedra superba* Kützing, *Synedra tabulata* (Agardh) Kützing, *Synedra tabulata* var. *acuminata* (Grunow) Hustedt, *Synedra toxoneides* Castracane, *Synedra ulna* (Nitzsch) Ehrenberg, *Synedra ulna* var. *biceps* (Kützing) Schönfeldt, *Synedra undulata* (J. W. Bailey) W. Smith

Synedrosphenia gomphonema (Janisch) Hustedt

Tabellaria sp., *Tabellaria fenestrata* (Lyngbye) Kützing, *Tabellaria flocculosa* (Roth) Kützing

Tetracyclus sp.

Thalassionema nitzschioides (Grunow) Mereschkowsky

Thalassiothrix sp., *Thalassiothrix longissima* Cleve and Grunow, *Thalassiothrix mediterranea* Pavillard

Toxarium undulatum Bailey

Tropidoneis sp., *Tropidoneis lepidoptera* (Gregory) Cleve, *Tropidoneis seriata* Cleve

Dinophyceae

Prorocentrales

Prorocentrum aporum (Schiller) Dodge, *Prorocentrum balticum* (Lohmann) Loeblich III, *Prorocentrum compressum* (Bailey) Abe, *Prorocentrum dentatum* Stein, *Prorocentrum gracile* Schutt, *Prorocentrum lima* (Ehrenberg) Dodge, *Prorocentrum maximum* (Gourret) Schiller, *Prorocentrum micans* Ehrenberg, *Prorocentrum minimum* (Pavillard) Schiller, *Prorocentrum ovum* (Schiller) Dodge, *Prorocentrum rostratum* Stein, *Prorocentrum rotundatum* Schiller, *Prorocentrum scutellum* Schröder, *Prorocentrum triestinum* Schiller, *Prorocentrum vaginulum* (Stein) Dodge

Dinophysiales

Amphisolenia sp., *Amphisolenia bidentata* Schröder, *Amphisolenia globifera* Stein

Ceratocorys horrida Stein

Dinophysis sp., *Dinophysis acuminata* Claparede and Lachmann, *Dinophysis acuta* Ehrenberg, *Dinophysis caudata* Saville-Kent, *Dinophysis diegensis* Kofoid, *Dinophysis fortii* Pavillard, *Dinophysis lachmannii* Paulsen, *Dinophysis monacantha* Kofoid and Skogsberg, *Dinophysis norvegica* Claparede and Lachmann, *Dinophysis ovum* Schutt, *Dinophysis pulchella* (Lebour) Balech, *Dinophysis punctata* Jørgensen, *Dinophysis rotundata* Claparede and Lachmann, *Dinophysis sacculus* Stein, *Dinophysis schroderi* Pavillard, *Dinophysis schuettii* Murray and Whitting, *Dinophysis tripos* Gourret

Ornithocercus sp., *Ornithocercus magnificus* Stein

Phalacroma sp.

Gymnodiniales

Akashiwo sanguinea (Hiraska) G. Hansen

(continued)

Table I: continued

Amphidinium sp., *Amphidinium acutissimum* Schiller, *Amphidinium acutum* Lohmann, *Amphidinium bipes* Herdman, *Amphidinium carterae* Hulburt, *Amphidinium crassum* Lohmann, *Amphidinium extensum* Wulff, *Amphidinium lacustre* Stein, *Amphidinium latum* Lebour, *Amphidinium longum* Lohmann, *Amphidinium operculatum* Claparede and Lachmann, *Amphidinium ovoideum* (Lemmermann) Lemmermann, *Amphidinium schroederi* Schiller, *Amphidinium sphenoides* Wulff, *Amphidinium steinii* (Lemmermann) Kofoid and Swezy, *Amphidinium turbo* Kofoid and Swezy, *Amphidinium wislouchi* Hulburt

Cochlodinium brandtii Wulff, *Cochlodinium helicoides* Lebour, *Cochlodinium polykrikoides* Margelef

Gymnodinium sp., *Gymnodinium arcticum* Wulff, *Gymnodinium boguensis* Campbell, *Gymnodinium coeruleum* Dogiel, *Gymnodinium costatum* Kofoid and Swezy, *Gymnodinium danicans* Campbell, *Gymnodinium dissimile* Kofoid and Swezy, *Gymnodinium flavum* Kofoid and Swezy, *Gymnodinium fuscum* (Ehrenberg) Stein, *Gymnodinium marinum* Kent, *Gymnodinium simplex* (Lohmann) Kofoid and Swezy, *Gymnodinium thompsonii* I. Kisselev, *Gymnodinium uberrimum* Kofoid and Swezy, *Gymnodinium verruculosum* Campbell

Gyrodinium sp., *Gyrodinium estuariale* Hulburt, *Gyrodinium fusiforme* Kofoid and Swezy, *Gyrodinium lachrymal* (Meunier) Kofoid and Swezy, *Gyrodinium spirale* (Bergh) Kofoid and Swezy, *Gyrodinium uncatenum* Hulburt, *Gyrodinium undulans* Hulburt

Katodinium asymmetricum (Massart) Loeblich III

Karlodinium micrum (Leadbeater and Dodge) J. Larsen

Oxyrrhis marina Dujardin

Polykrikos kofoidii Chatton

Noctilucales

Noctiluca scintillans (Macartney) Kofoid and Swezy

Pyrocystales

Dissodium asymmetricum (Mangin) Loeblich III

Peridinales

Amphidoma sp.

Ceratium sp., *Ceratium arietinum* P. T. Cleve, *Ceratium candelabrum* (Ehrenberg) Stein, *Ceratium carolinianum* (Bailey) Jorgensen, *Ceratium carriense* Gourret, *Ceratium contortum* (Gourret) Cleve, *Ceratium declinatum* Karsten, *Ceratium extensum* (Gourret) Cleve, *Ceratium furca* (Ehrenberg) Claparede and Lachman, *Ceratium fusus* (Ehrenberg) Dujardin, *Ceratium hirundinella* (Müller) Schrank, *Ceratium horridum* (P. T. Cleve) Gran, *Ceratium inflatum* (Kofoid) Jorgenson, *Ceratium kofoidii* Jorgensen, *Ceratium limulus* Gourret, *Ceratium lineatum* (Ehrenberg) Cleve, *Ceratium longinum* Karsten, *Ceratium longipes* (Bailey) Gran, *Ceratium macroceros* (Ehrenberg) Vanhoffen, *Ceratium massiliense* (Gourret) Jorgensen, *Ceratium minutum* Jorgensen, *Ceratium pentagonum* Gourret, *Ceratium pulchellum* f. *semipulchellum* Jorgensen, *Ceratium setaceum* Jorgensen, *Ceratium teres* Kofoid, *Ceratium trichoceros* (Ehrenberg) Kofoid, *Ceratium tripos* (Müller) Nitzsch

Cladopyxis claytonii R. W. Holmes

Diplopsalis lenticula Bergh

Diplopsalopsis minor (Paulsen) Pavillard

Glenodinium sp., *Glenodinium armatum* Levander, *Glenodinium gymnodinium* Penard

Gonyaulax sp., *Gonyaulax conjuncta* Wood, *Gonyaulax diacantha* (Meunier) Schiller, *Gonyaulax digitale* (Pouchet) Kofoid, *Gonyaulax minuta* Kofoid and Michener, *Gonyaulax monocantha* Pavillard, *Gonyaulax polygramma* Stein, *Gonyaulax spinifera* (Claparede and Lachmann) Diesing, *Gonyaulax triacantha* Jorgensen, *Gonyaulax verior* Sournia

Heteraulacus polyedricus (Pouchet) Drugg and Loeblich

Heterocapsa rotundata (Lohmann) Hansen, *Heterocapsa triquetra* (Ehrenberg) Stein

Oblea rotunda (Lebour) Balech

Oxytoxum crassum Schiller, *Oxytoxum milneri* Murray and Whitting, *Oxytoxum parvum* Schiller, *Oxytoxum reticulatum* (Stein) Butschli, *Oxytoxum sceptrum* (Stein) Schröder, *Oxytoxum scolopax* Stein, *Oxytoxum variabile* Schiller

Peridinium sp., *Peridinium aciculiferum* Lemmermann, *Peridinium cinctum* Ehrenberg, *Peridinium inconspicuum* Lemmermann, *Peridinium wisconsinense* (Eddy) Kützing

Protoperidinium sp., *Protoperidinium avellana* (Meunier) Balech, *Protoperidinium bipes* (Paulsen) Balech, *Protoperidinium breve* (Paulsen) Balech, *Protoperidinium brevipes* (Paulsen) Balech, *Protoperidinium brochii* (Kofoid and Swezy) Balech, *Protoperidinium cerasus* (Paulsen) Balech, *Protoperidinium cinctum* (Ehrenberg) Balech, *Protoperidinium claudicans* (Paulsen) Balech, *Protoperidinium conicoides* (Paulsen) Balech, *Protoperidinium conicum* (Gran) Balech, *Protoperidinium decipiens* (Jørgensen) Parke and Dodge, *Protoperidinium depressum* (Bailey) Balech, *Protoperidinium diabolum* (Cleve) Balech, *Protoperidinium divergens* (Ehrenberg) Balech, *Protoperidinium fimbriatum* (Meunier) Balech, *Protoperidinium globulum* (Stein) Balech, *Protoperidinium granii* (Ostenfeld) Balech, *Protoperidinium leonis* (Pavillard) Balech, *Protoperidinium*

(continued)

Table I: continued

minutum (Kofoid) Loeblich III, *Protoperidinium mite* (Pavillard) Balech, *Protoperidinium nipponicum* (Abe) Balech, *Protoperidinium oblongum* (Aurivillius) Parke and Dodge, *Protoperidinium oceanicum* (Vanhoffen) Balech, *Protoperidinium orbiculare* (Paulsen) Balech, *Protoperidinium ovatum* (Pouchet) Balech, *Protoperidinium pallidum* (Ostenfeld) Balech, *Protoperidinium pellucidum* Bergh, *Protoperidinium pendunculatum* (Schutt) Balech, *Protoperidinium pentagonum* (Gran) Balech, *Protoperidinium quarnerense* (Schröder) Balech, *Protoperidinium steinii* (Jørgensen) Balech, *Protoperidinium subinerme* (Paulsen) Balech, *Protoperidinium thorianum* (Paulsen) Balech

Pyrocystis sp., *Pyrocystis hamulus* Cleve

Pyrodinium bahamense Wall and Dale

Pyrophacus sp., *Pyrophacus horologium* Stein

Scrippsiella precaria Montresor and Zingone, *Scrippsiella trochoidea* (Stein) Loeblich III

Zygabikodinium lenticulatum Loeblich and Loeblich

Dinamoebales

Pfiesteria piscicida Steidinger and Burkholder, *Pfiesteria shumwayae* Glasgow and Burkholder

Coccolithophoridaceae

Isochrysidales

Emiliania huxleyi (Lohmann) Hay and Mohler

Hymenomonas carterae (Braarud and Fagerland) Braarud

Coccosphaerales

Acanthoica quattrospina Lohmann

Calciosolenia granii Schiller, *Calciosolenia murrayi* Gran

Calyptrosphaera oblonga Lohmann

Discosphaera tubifer (Murray and Blackman) Ostenfeld

Michaelsarsia elegans Gran

Ophiaster hydroideus (Lohmann) Lohmann

Pontosphaera syracusana Lohmann

Rhabdosphaera claviger Murray and Blackman, *Rhabdosphaera hispida* Lohmann, *Rhabdosphaera longistylis* Schiller, *Rhabdosphaera stylifer* Lohmann

Scyphosphaera apsteinii Lohmann

Syracosphaera histrica Kamptner, *Syracosphaera pulchra* Lohmann

Raphidophyceae

Chattonella subsalsa Biecheler, *Chattonella verruculosa* Hara and Chihara

Heterosigma akashiwo (Hada) Hada ex Hada et Chihara

Olisthodiscus sp., *Olisthodiscus luteus* N. Carter

Cyanophyceae (cyanoprokaryotes)

Chroococcales

Aphanocapsa sp., *Aphanocapsa delicatssima* West and West, *Aphanocapsa elachista* West and West, *Aphanocapsa grevillei* Rabenhorst, *Aphanocapsa holsatica* (Lemmermann) Cronberg and Komárek, *Aphanocapsa pulchra* Rabenhorst

Aphanothece sp., *Aphanothece gelatinosa* (Henn) Lemmermann

Chroococcus sp., *Chroococcus dispersus* (Keissler) Lemmermann, *Chroococcus dispersus* var. *minor* G. Smith, *Chroococcus limneticus* Lemmermann, *Chroococcus limneticus* var. *elegans* G. M. Smith, *Chroococcus prescottii* Drouet and Daily, *Chroococcus turgidus* (Kützing) Nägeli

Coelosphaerium sp.

Dactylococcopsis sp., *Dactylococcopsis acicularis* Lemmermann, *Dactylococcopsis fascicularis* Lemmermann, *Dactylococcopsis raphidioides* Hansgirg, *Dactylococcopsis raphidioides* f. *falciformis* Prinz

Democarpa swirenkoi Schirsch

Entophysalis deusta (Meneghini) Drouet and Daily

Gloecapsa sp., *Gloecapsa aeruginosa* Kützing, *Gloecapsa minima* (Keissler) Hollerbach, *Gloecapsa linearis* Nägeli

Gloeothece sp., *Gloeothece linearis* f. *composita* G. Smith

Gomphosphaeria sp., *Gomphosphaeria aponina* Kützing, *Gomphosphaeria Naegeliana* (Unger) Lemmermann

Johannesbaptistia pellucida (Dickie) Taylor and Drouet

Marssoniella elegans Lemmermann

(continued)

Table I: continued

Merismopedia sp., *Merismopedia convoluta* Brébisson, *Merismopedia elegans* Braun, *Merismopedia elegans* var. *major* G. Smith, *Merismopedia glauca* (Ehrenberg) Nägeli, *Merismopedia marssonii* Lemmermann, *Merismopedia thermalis* Kützing, *Merismopedia punctata* Meyen, *Merismopedia tenuissima* Lemmermann

Microcystis aeruginosa Kützing, *Microcystis firma* (Brébisson and Lemmermann) Schmidle, *Microcystis incerta* Lemmermann, *Microcystis viridis* (Braun in Rabenhorst) Lemmermann

Rhabdoderma sp., *Rhabdoderma lineare* Schmidle and Lauterborn, *Rhabdoderma sigmoidea* f. *minor* Moore and Carter

Rhabdogloea elenkinii (Roll) Komárek and Anagnostidis, *Rhabdogloea smithii* (R. and F. Chodat) Komárek

Snowella lacustris (Chodat) Komárek and Hindák

Synechococcus sp., *Synechococcus elongates* (Nägeli) Nägeli

Synechocystis sp., *Synechocystis salina* Wislouch

Woronichinia elorantae Komárek and Komarkova-Legnerova, *Woronichinia fusca* (Skuja) Komárek and Hindák

Nostocales

Anabaena sp., *Anabaena aequalis* Borge, *Anabaena affinis* Lemmerman, *Anabaena angstumalis* var. *marchica* Lemmerman, *Anabaena circinalis* Rabenhorst, *Anabaena confervoides* Reinsch, *Anabaena flos-aquae* Brébisson, *Anabaena limnetica* G. M. Smith, *Anabaena recta* Komárek and Kovacik, *Anabaena reniformis* Lemmermann, *Anabaena solitaria* Klebahn, *Anabaena spiroides* Klebahn, *Anabaena spiroides* var. *crassa* Lemmermann, *Anabaena wisconsinense* Prescott

Anabaenopsis raciborskii Woloszynska

Aphanizomenon flos-aquae (L) Ralfs, *Aphanizomenon issatschenkoi* (Ussaczew) Proschkina-Lavrenko

Calothrix sp., *Calothrix parietina* Thuret

Cylindrospermum doryphorum Bruhl and Biswas

Nodularia sp., *Nodularia harveyana* (Thwaites) Thuret, *Nodularia spumigena* f. *litorea* (Kützing) Elenkin

Nostoc sp., *Nostoc commune* Vaucher

Richelia intracellularis Schmidt

Oscillatoriales

Limnothrix planktonica (Woloszynska) Meffert

Lyngbya sp., *Lyngbya circumereta* G. S. West, *Lyngbya hieronymusi* Lemmermann, *Lyngbya planctonica*

Microcoleus sp., *Microcoleus lyngbyaceus* (Kützing) Crouan

Oscillatoria sp., *Oscillatoria angustissima* West and West, *Oscillatoria erythraea* (Ehrenberg) Kützing, *Oscillatoria granulata* Gardner, *Oscillatoria irrigua* (Kützing) Gomont, *Oscillatoria lemmermannii* Wolosz, *Oscillatoria limosa* C. A. Agardh, *Oscillatoria lutea* Agardh, *Oscillatoria mirabilis* Bocher, *Oscillatoria pseudominima* Skuja, *Oscillatoria subbrevis* Schimdle, *Oscillatoria submembranacea* Ardissone and Strafforella, *Oscillatoria terebriformis* Agardh

Phormidium sp., *Phormidium amphibium* (Agardh) Anagnostidis and Komárek, *Phormidium musicola* Naumann and Huber-Pestalozzi, *Phormidium splendidum* (Greville) Anagnostidis and Komárek

Planktolyngbya contorta (Lemmermann) Anagnostidis and Komárek, *Planktolyngbya litoralis* (Häyrén) Komárek and Hindák, *Planktolyngbya subtilis* (W. West) Anagnostidis and Komárek

Planktothrix agardhii Anagnostidis and Komárek, *Planktothrix limnetica* (Lemmermann) Komárek and Anagnostidis, *Planktothrix limnetica* f. *acicularis* (Nygaard) V. Poljanskij

Pseudanabaena limnetica (Lemmermann) Komárek

Raphidiopsis curvata Fritsch and Rich

Schizothrix sp., *Schizothrix arenaria* (Berkeley) Gomont, *Schizothrix calcicola* (Agardh) Gomont, *Schizothrix tenerrima* (Gomont) Drouet

Spirulina sp., *Spirulina laxa* Smith, *Spirulina major* Kützing, *Spirulina subsalsa* Oersted

Trichodesmium lacustre Klebahn

Euglenophyceae

Euglenales

Characium limneticum Lemmerman

Euglena sp., *Euglena acus* Ehrenberg, *Euglena agilis* Carter, *Euglena convoluta* Korshikov, *Euglena deses* Ehrenberg, *Euglena ehrenbergii* Klebs, *Euglena elastica* Prescott, *Euglena fusca* (Klebs) Lemmermann, *Euglena gracilis* Klebs, *Euglena mutabilis* Schmitz, *Euglena mutabilis* var. *mainxi* Pringsheim, *Euglena oblonga* Schmitz, *Euglena oxyuris* Schmarda, *Euglena polymorpha* Dangeard, *Euglena proxima* Dangeard, *Euglena pumila* Campbell, *Euglena spirogyra* Ehrenberg, *Euglena tripteris* (Dujardin) Klebs, *Euglena virdis* (O. F. Müller) Ehrenberg

Eutreptia sp., *Eutreptia lanowii* Steuer, *Eutreptia marina* Cunha, *Eutreptia viridis* Perty

(continued)

Table I: continued

Leptocinclis sp., *Leptocinclis ovum* var. *gracilicauda* Deflandre, *Leptocinclis sphagnophila* Lemmermann

Phacus sp., *Phacus caudatus* Hubner, *Phacus curvicauda* Swirenko, *Phacus latus* Pochmann, *Phacus lemmermanni* (Swirenko) Skvortzow, *Phacus longicauda* (Ehrenberg) Dujardin, *Phacus monilatus* Stokes, *Phacus orbicularis* Huebner, *Phacus perkinensis* Skvortz, *Phacus suecicus* Lemmermann, *Phacus triqueter* Dujardin

Rhabdomonas spiralis Pringsheim

Strombomonas affinis (Lemmermann) Deflandre, *Strombomonas borysteniensis* (Roll) Popova, *Strombomonas asymmetrica* (Roll) Popova, *Strombomonas australica* Deflandre

Trachelomonas sp., *Trachelomonas acanthophora* Stokes, *Trachelomonas acanthostoma* (Stokes) Deflandre, *Trachelomonas armata* var. *longa* Deflandre, *Trachelomonas bulla* (Stein) Deflandre, *Trachelomonas charkowiensis* Swirenko, *Trachelomonas globularis* var. *boyeri* Conrad, *Trachelomonas hispida* (Perty) Stein, *Trachelomonas hispida* var. *coronata* Lemmermann, *Trachelomonas intermedia* Dangeard, *Trachelomonas planctonica* var. *oblonga* Drezepolski, *Trachelomonas raciborskii* Woloszynska, *Trachelomonas regulosa* Deflandre, *Trachelomonas scabra* var. *longicollis* Playfair, *Trachelomonas similis* Stokes, *Trachelomonas superba* Deflandre, *Trachelomonas superba* var. *duplex* Deflandre, *Trachelomonas varians* Deflandre, *Trachelomonas verrucosa* Stokes, *Trachelomonas volvocina* Enrenberg, *Trachelomonas volvocina* var. *punctata* Playfair

Chlorophyceae

Volvocales

Asterococcus limneticus G. M. Smith

Carteria cordiformis (Carter) Diesing, *Carteria fornicata* Nygaard

Chlamydomonas sp., *Chlamydomonas pertyi* Goroshankin

Eudorina sp., *Eudorina cylindrica* Korschikov, *Eudorina elegans* Eherenberg

Gonium sp., *Gonium pectorale* O. F. Müller

Pleodorina sp.

Phacotus sp., *Phacotus lenticularis* Ehrenberg

Volvox aureus Ehrenberg, *Volvox tertius* Meyer

Zygnematales

Closterium sp., *Closterium acutum* Brébisson, *Closterium aciculare* T. West, *Closterium acutum* Brébisson, *Closterium archerianum* Cleve, *Closterium dianae* Ehrenberg, *Closterium lineatum* Ehrenberg, *Closterium parvulum* Nägeli, *Closterium pronum* Brébisson, *Closterium setaecum* Ehrenberg

Coelastrum sp., *Coelastrum cambricum* Archer, *Coelastrum microporum* Nägeli, *Coelastrum reticulatum* (Dangeard) Senn, *Coelastrum sphaericum* Nägeli

Coenochloris mucosa (Kors.) Hindák

Cosmarium sp., *Cosmarium alpestre* Roy, *Cosmarium contractum* Kirchner, *Cosmarium costatum* West and West, *Cosmarium cynthia* Denot, *Cosmarium ornatum* Ralfs, *Cosmarium rectangulare* Grunow, *Cosmarium subreniforme* Nordstedt, *Cosmarium tenue* Archer, *Cosmarium turpinii* Brébisson

Desmidium sp., *Desmidium baileyi* (Ralfs) Nordstedt, *Desmidium grevillii* Kützing

Gonatozygon brebissonii Debary

Euastrum sp., *Euastrum abruptum* West and West, *Euastrum gayanum* DeToni

Hyalotheca sp., *Hyalotheca dissiliens* var. *tatrica* Raciborski

Micrasterias sp., *Micrasterias johnsonii* West and West, *Micrasterias pinnatifida* (Kützing) Ralfs, *Micrasterias radiata* Hass, *Micrasterias truncata* (Corda) Brébisson

Mougeotia sp.

Penium sp.

Pleurocapsa minor Hansgirg

Pleurotaenium sp., *Pleurotaenium nodulosum* (Brébisson) DeBary, *Pleurotaenium subcoronulatum* var. *detum* (Turner) West and West, *Pleurotaenium trabecula* Nägeli, *Pleurotaenium tridentulum* (Wolle) West

Spirogyra sp., *Spirogyra crassa* Kützing, *Spirogyra tenuissima* Kützing

Spondylosium planum (Wolle) West and West, *Spondylosium pygmaeum* Rabenhorst

(continued)

Table I: continued

Staurastrum sp., *Staurastrum americanum* (West and West) G. M. Smith, *Staurastrum chaetoceras* (Schröder) G. S. Smith, *Staurastrum cingulum* var. *floridense* Scott and Gronblad, *Staurastrum curvatum* W. West, *Staurastrum grande* Bulnheim, *Staurastrum leptocladum* Nordstedt, *Staurastrum leptocladum* var. *cornumtum* Wille, *Staurastrum leptocladum* var. *insigne* West and West, *Staurastrum manfeldtii* var. *flumenense* Schumacher, *Staurastrum paradoxum* Meyen, *Staurastrum paradoxum* var. *cingulum* Kim, *Staurastrum pentacerum* G. M. Smith, *Staurastrum quadricuspidatum* Turner, *Staurastrum tetracerum* Ralfs

Xanthidinium sp., *Xanthidinium antilopeum* Ehrenberg ex Kützing, *Xanthidinium subhastiferum* var. *towerii* (Cushman) G. W. Smith

Zygnema sp.

Cladophorales

Cladophora sp.

Chaetophorales

Chaetosphaeridium globosum (Nordstedt) Klebahn

Ulotrichales

Geminella subtilissima (Langerheim) Printz

Hormidium Klebsii G. M. Smith

Koliella longiseta (Vischer) Hindák

Radiophilum flavescens G. S. West

Ulothrix sp., *Ulothrix subtilissima* Rabenhorst, *Ulothrix variabilis* Kützing

Tetrasporales

Dispora crucigenioides Printz

Gloeocystis vesiculosa Nägeli

Palmodictyon varium (Nägeli) Lemmermann

Oedogoniales

Oedogonium sp.

Chlorococcales

Acanthosphaera zachariasii Lemmermann

Actinastrum sp., *Actinastrum hantzschii* Lagerheim, *Actinastrum hantzschii* var. *elongatum* G. M. Smith, *Actinastrum hantzschii* var. *fluviatile* Schröder

Ankistrodesmus sp., *Ankistrodesmus braunii* (Nåegeli) Bruunthaler, *Ankistrodesmus convolutus* Chorda, *Ankistrodesmus falcatus* (Corda) Ralfs, *Ankistrodesmus falcatus* var. *acicularis* (Braun) West, *Ankistrodesmus falcatus* var. *tumidus* (West and West) G. S. West, *Ankistrodesmus falcatus* var. *mirabilis* G. S. West, *Ankistrodesmus gracilis* (Reinsch) Korschikov, *Ankistrodesmus longissimus* (Lemmermann) Wille, *Ankistrodesmus spiralis* (Turner) Lemmermann

Arthrodesmus sp., *Arthrodesmus incus* var. *extensus* Anderson, *Arthrodesmus octocornis* Ehrenberg, *Arthrodesmus sublatus* Kützing, *Arthrodesmus validus* var. *incrassatus* Scott and Gronblad

Botryococcus sp., *Botryococcus braunii* Kützing, *Botryococcus protuberans* West and West, *Botryococcus sudeticus* Lemmerman

Chlorella marina Butcher, *Chlorella saccharophilia* var. *ellipsoidea* (Kruger) Gerneck, *Chlorella salina* Kufferath, *Chlorella vulgaris* Beijerinck

Choricystis sp.

Closteriopsis acicularis (G. Smith) Belcher and Swale, *Closteriopsis longissima* Lemmermann

Coelastrum microsporum Nägeli

Crucigenia sp., *Crucigenia apiculata* (Lemmermann) Schmidle, *Crucigenia crucifera* (Wolle) Collins, *Crucigenia fenestrata* Schmidle, *Crucigenia irregularis* Wille, *Crucigenia lauterbornii* Schmidle, *Crucigenia quadrata* Morren, *Crucigenia rectangularis* (A. Braun) Gay, *Crucigenia smithii* (Bourr and Mangin) Komárek, *Crucigenia tetrapedia* (Kirchner) West and West

Desmodesmus abundans (Kirchner) Hegewald, *Desmodesmus armatus* (Chodat) Hegewald, *Desmodesmus armatus* var. *bicaudatus* (Guglielmetti) Hegewald, *Desmodesmus denticulatus* (Lagerheim) Hegewald, *Desmodesmus denticulatus* var. *recurvatus* (Schumacker) Hegewald, *Desmodesmus hystrix* (Lagerheim) Hegewald, *Desmodesmus intermedius* (Chodat) Hegewald, *Desmodesmus maximus* (West and West) Hegewald, *Desmodesmus opoliensis* (Richter) Hegewald, *Desmodesmus perforatus* (Lemmermann) Hegewald, *Desmodesmus quadricauda* (Turpin) Hegewald

Dictyosphaerium sp., *Dictyosphaerium ehrenbergianum* Nägeli, *Dictyosphaerium planctonicum* Tiffany and Ahlstrom, *Dictyosphaerium pulchellum* Wood, *Dictyosphaerium tetrachotomium* Printz

Didymogenes palatine Schmidle

Elakatothrix gelatinosa Wille

Errerella bornhemiensis Conrad

(continued)

Table I: continued

Golenkinia radiata R. Chodat

Franceia sp., *Franceia elongata* Korschikov, *Franceia ovalis* Lemmermann

Kirchneriella sp., *Kirchneriella contorta* (Schmidle) Bohlin, *Kirchneriella elongata* G. M. Smith, *Kirchneriella irregularis* var. *spiralis* (Smith) Korschikov, *Kirchneriella lunaris* (Kirchner) Moebius, *Kirchneriella obesa* (W. West) Schmidle, *Kirchneriella obesa major* (Bernard) G. M. Smith, *Kirchneriella subsolitaria* G. S. West

Lagerheimia sp., *Lagerheimia ciliata* (Langerheim) Chodat, *Lagerheimia citriformis* (Snow) Collins, *Lagerheimia longiseta* (Lemmermann) Wille

Micractinium sp., *Micractinium crassisetum* Hortobagyi, *Micractinium pusillum* Fresenius, *Micractinium pusillum* var. *elegans* G. M. Smith

Microspora sp., *Microspora lauterbomii* Schmidle, *Microspora quadrata* Hazen

Monoraphidium arcuatum (Korscikoviella) Hindák, *Monoraphidium contortum* (Thuret) Komárková-Legnerová, *Monoraphidium griffithii* (Berkel) Komárková-Legnerová, *Monoraphidium komarkovae* Nygaard, *Monoraphidium minutum* (Nägeli) Komárková-Legnerová, *Monoraphidium obtusum* (Korschikov) Komárková-Legnerová, *Monoraphidium pusillum* (Printz) Komárková-Legnerová, *Monoraphidium tortile* (West and West) Komárek

Nannochloris sp., *Nannochloris atomus* Butcher

Nephrocytium agardhianum Nägeli, *Nephrocytium limneticum* (G. M. Smith) G. M. Smith

Oocystis sp., *Oocystis Borgei* Snow, *Oocystis coronata* Lemmermann, *Oocystis elliptica* W. West, *Oocystis parva* West and West, *Oocystis solitaria* Wittrock

Pandorina sp., *Pandorina morum* (Müller) Bory

Pediastrum sp., *Pediastrum angulosum* (Ehrenberg) Meneghini, *Pediastrum biradiatum* Meyen, *Pediastrum boryanum* (Turpin) Meneghini, *Pediastrum boryanum* var. *longicorne* Reinsch, *Pediastrum duplex* Meyen, *Pediastrum duplex* var. *gracilimum* West and West, *Pediastrum duplex* var. *inflata* Wolosz, *Pediastrum duplex* var. *reticulatum* Lagerheim, *Pediastrum duplex* var. *rotundatum* Lucks, *Pediastrum duplex* var. *subgranulatum* Raciborski, *Pediastrum glanduliferum* Bennet, *Pediastrum muticum* Kützing, *Pediastrum obtusum* Lucks, *Pediastrum simplex* (Meyen) Lemmermann, *Pediastrum simplex* var. *duodenarium* (Bailey) Rabenhorst, *Pediastrum tetras* (Ehrenberg) Ralfs, *Pediastrum tetras* var. *tetraodon* Rabenhorst

Polyedriopsis spinulosa (Schmidle) Schmidle

Quadrigula sp., *Quadrigula chodatii* G. M. Smith, *Quadrigula closterioides* (Bohlim) Printz, *Quadrigula lacustris* (Chodat) G. M. Smith, *Quadrigula phitzeri* (Schröder) G. M. Smith

Scenedesmus sp., *Scenedesmus acuminatus* (Lagerheim) Chodat, *Scenedesmus arcuatus* (Lemmermann) Lemmermann, *Scenedesmus arcuatus* var. *platydisca* G. M. Smith, *Scenedesmus bernardii* G. Smith, *Scenedesmus bijuga* (Turpin) Lagerheim, *Scenedesmus bijuga* var. *alternans* (Reinsch) Hansgirg, *Scenedesmus costato* var. *alternans* (Reinsch) Hansgirg, *Scenedesmus dimorphus* (Turpin) Kützing, *Scenedesmus ecornis* (Ehrenberg) Chodat, *Scenedesmus incrassatulus* Bohin, *Scenedesmus linearis* Komarek, *Scenedesmus obliquus* (Turpin) Kützing

Schroederia planctonica (Skuja) Philipose, *Schroederia setigera* (Schröder) Lemmermann

Selenastrum sp., *Selenastrum gracile* Reinsch, *Selenastrum minutum* (Nägeli) Collins, *Selenastrum westii* G. M. Smith

Tetradesmus smithii Prescott

Tetraëdron sp., *Tetraëdron arthrodesmiforme* Wolszynska, *Tetraëdron caudatum* (Corda) Hansgirg, *Tetraëdron cruciatum* West and West, *Tetraëdron gracile* (Reinsch) Hansgirg, *Tetraëdron hastatum* (Reinsch) Hansgrig, *Tetraëdron limneticum* Borge, *Tetraëdron lobulatum* (Nägeli) Hansgirg, *Tetraëdron minimum* (Braun) Hansgirg, *Tetraëdron muticum* (Braun) Hansgirg, *Tetraëdron pentaedricum* West and West, *Tetraëdron regulare* Kützing, *Tetraëdron regulare* var. *incus* Teiling, *Tetraëdron regulare* var. *torsum* Brunnthaler, *Tetraëdron triacanthum* Korschikov, *Tetraëdron trigonum* (Nägeli) Hansgirg, *Tetraëdron trigonum* var. *gracile* (Reinsch) DeToni

Tetrastrum sp., *Tetrastrum elegans* Playfair, *Tetrastrum glabrum* (Roll) Ahlstrom and Tiffany, *Tetrastrum heteracanthum* (Nordstedt) Chodat, *Tetrastrum staurogeniaeforme* (Schröder) Lemmermann

Treubaria setigera (Archer) G. M. Smith

Westella botryoides (W. West) de Wildermann

Prasinophyceae

Chlorodendrales

Heteromastix pyriformis (Carter) Manton, *Heteromastix rotunda* (Carter) Manton

Pyramimonas sp., *Pyramimonas amylifer* Conrad, *Pyramimonas grossii* Parke, *Pyramimonas micron* Conrad and Kufferath, *Pyramimonas obovata* N. Carter, *Pyramimonas plurioculata* Butcher, *Pyramimonas torta* Conrad and Kufferath

Tetraselmis sp., *Tetraselmis gracilis* (Kylin) Butcher, *Tetraselmis maculata* Butcher

Cryptophyceae

Cryptomonadales

Chilomonas marina (Braarud) Halldal

(continued)

Table I: continued

Chroomonas amphioxeia (Conrad and Kufferath) Butcher, *Chroomonas salina* (Wislouch) Butcher, *Chroomonas vectensis* Carter
Cryptomonas erosa Ehrenberg, *Cryptomonas erosa* var. *reflexa* Marsson, *Cryptomonas massonii* Skuja, *Cryptomonas ovata* Ehrenberg, *Cryptomonas ovata* var. *curvata* (Eherenberg) Lemmermann, *Cryptomonas phaseolus* Skuja, *Cryptomonas pseudobaltica* Butcher, *Cryptomonas reflexa* Skuja, *Cryptomonas rostrata* Troitzk, *Cryptomonas rostrella* Lucas, *Cryptomonas stigmatica* Wislouch
Hemiselmis sp.
Rhodomonas minuta Skuja, *Rhodomonas ovata* Ehrenberg
Chrysophyceae
Ochromonadales
Calycomonas sp., *Calycomonas gracilis* Lohmann, *Calycomonas wulffii* Conrad and Kufferath
Centritractus belanophorus Lemmermann, *Centritractus brunneus* Fott, *Centritractus capilifer* Pascher, *Centritractus globulosus* Pascher
Chromulina parvula Conrad, *Chromulina wislouchiana* Bourelly
Chrysococcus minutus (Fritsch) Nygaard, *Chrysococcus ornatus* Pascher, *Chrysococcus rufescens* Klebs, *Chrysococcus tesselatus* Fritsch
Dinobryon sp., *Dinobryon bavaricum* Imhof, *Dinobryon calciformis* Bachmann, *Dinobryon cylindricum* Imhof, *Dinobryon divergens* Imhof, *Dinobryon petiolatum* Willen, *Dinobryon sertularia* Ehrenberg, *Dinobryon sociale* Ehrenberg
Kephyrion sp., *Kephyrion ovale* (Lackey) Huber-Pestalozzi
Ochromonas sp., *Ochromonas caroliniana* Campbell, *Ochromonas minuscula* Conrad, *Ochromonas variabilis* Meyer
Pseudotetraedron neglectum Pascher
Paulinella ovalis (Wulff) Johnson, Hargraves and Sieburth
Rhizochrysis limnetica G. M. Smith
Synurales
Mallomonas sp., *Mallomonas caudata* Conrad, *Mallomonas producta* Ivanov, *Mallomonas tonsurata* Teiling
Synura sp., *Synura adamsii* G. M. Smith, *Synura uvella* Ehrenberg
Chrysophaerales
Aureococcus anophagefferens Hargraves and Sieburth
Stylococcales
Lagynion cystodinii Pascher
Dictyochophyceae
Pedinellales
Apedinella radians (Lohmann) Campbell
Dictyochales
Dictyocha crux Ehrenberg, *Dictyocha fibula* Ehrenberg
Distephanus speculum (Ehrenberg) Haeckel
Mesocena polymorpha Lemmermann
Prymnesiophyceae
Prymnesiales
Chrysochromulina sp., *Chrysochromulina minor* Parke and Manton
Pavlovales
Pavlova homersandii Campbell, *Pavlova salina* (Carter) Green
Isochrysidales
Isochrysis galbana Parke
Xanthophyceae
Tribonematales
Tribonema sp., *Tribonema aequale* Pascher, *Tribonema affine* West, *Tribonema ambiguum* Skuja, *Tribonema minus* (Wille) Hazen, *Tribonema monochloron* Pascher and Geitler, *Tribonema pyrenigerum* Pascher, *Tribonema subtilissimum* Pascher, *Tribonema viride* Pascher, *Tribonema vulgare* Pascher
Chloramoebales
Nephrochloris sp., *Nephrochloris salina* Carter
Mischococcales
Botrydiopsis arhiza Borzi, *Botrydiopsis eriensis* Snow

(continued)

Table I: continued

Characiopsis subulata (A. Braun) Gorzi
Dichotomococcus curvatus Korschikoff
Gleobotrys limneticus (G. M. Smith) Pascher
Goniochloris pulcherrima Pascher
Isthmochloron lobulatum (Nägeli) Skuja
Monodus sp., *Monodus guttula* Pascher
Ophiocytium capitatum var. *longispinum* Lemmermann, *Ophiocytium cochlerare* A. Braun
Pseudotetraedron neglectum Pascher
Tetraedriella spinigera Skuja

were with levels of *C. furca* in summer reported at $1 \times 10^{5-6}$ cells L^{-1} by Marshall (Marshall, 1995a) compared with highs indicated by Cowles (Cowles, 1930) of 23×10^{3} cells L^{-1}. These differences infer increased eutrophic conditions have accompanied these changes allowing increased floral concentrations to occur. These conditions would also be favorable in supporting the increased long-term trends in phytoplankton abundance and biomass within tidal tributaries of Chesapeake Bay, described by Marshall and Burchardt (Marshall and Burchardt, 2004a).

Seasonal composition and successional patterns

The seasonal succession was often initiated by a winter dinoflagellate bloom (e.g. *Heterocapsa rotundata*) in the upper oligo- and mesohaline regions of Maryland and Virginia tributaries and the mainstem Bay. The succession continued into spring, with a significant diatom bloom throughout each salinity region. At tidal freshwater river and Bay sites, plus the oligohaline sections of the estuary, the diatom *Skeletonema potamos* was a major component. The diatom bloom came as early as midwinter and has continued even into late spring, but maximum concentrations were generally attained between March and May. Other diatoms in these regions included *Aulacoseira distans*, *Aulacoseira granulate*, *C. choctawhatcheeana*, *Cyclotella meneghiniana*, *Leptocylindrus minimus* and several *Thalassiosira* spp. Accompanying this spring development were lesser concentrations of chlorophytes, cyanobacteria and cryptomonads, which increased in abundance as the diatom bloom diminished into late spring and early summer. Representative species within these categories were *Desmodesmus* spp., *Scenedesmus* spp., *Microcystis aeruginosa* and *Cryptomonas erosa*. The spring diatom bloom in the mesohaline and polyhaline regions of the Bay and its tributaries was dominated by *S. costatum*. *Cerataulina pelagica* and *D. fragilissimus* followed, with increasing abundance throughout the Bay by March and April. The common dinoflagellates and bloom producers in these regions were *P. minimum*, *Heterocapsa triquetra* and *H. rotundata*. Blooms of *Procentrum minimum*, *Karlodinium micrum*, *Cochlodinium polykrikoides*, *Akashiwo sanguinea* and *Scrippsiella trochoidea* were also common in mid-spring and the summer/autumn months in both the southern tributary regions and Chesapeake Bay (Marshall, 1995a).

The summer months contained a major successional shift with increased species diversity involving the major algal categories. Although many of the spring dominants continued to be present, their contribution to total algal abundance and biomass diminished. The tidal freshwater and oligohaline regions gained additional representation of chlorophytes and cyanobacteria. Depending on water quality conditions, there was decreased diatom dominance, with many of the cyanobacteria becoming common bloom producers (e.g. *Microcystis* spp., *Oscillatoria* spp., *Merismopedia* spp.). A greater diversity of diatoms was present compared with spring and included *Thalassiosira oestrupii* var. *venrickae*, *Thalassiosira pseudonana*, *Actinocyclus normanii* and several *Cyclotella* spp. Several major changes in floral dominance were associated with the higher salinity regions of the estuary. More numerous large-size diatom and dinoflagellate taxa were common, and the abundance of chlorophytes and cyanobacteria greatly diminished. The major exception to this pattern was high concentrations of autotrophic picoplankton composed primarily of cyanobacteria and, to a lesser degree, chlorophytes and others. These cyanobacteria typically produced a single summer maximum (Marshall, 1995b). Diatoms common during this period included *P. alata*, *G. striata*, *Guinardia delicatula*, *Chaetoceros* spp., *L. minimus*, *Cylindrotheca closterium*, *Pseudo-nitzschia* spp. and *Thalassiosira nordenskioeldii*. The dominant summer dinoflagellates were *A. sanguinea*, *P. minimum*, *P. micans*, *C. furca*, *K. micrum* and a variety of neritic species introduced to these Bay waters. Several unidentified cryptoperidiniopsoid dinoflagellates were

also common throughout the estuary from summer to early autumn. In the northern Bay mesohaline waters, phytoplankton numbers were dominated by small-sized taxa from several different categories. Cyanobacteria densities were seasonally high and were primarily composed of *M. aeruginosa* and *Merismopedia* spp., plus several *Oscillatoria* spp. and other filamentous taxa. Smaller-sized diatoms were prevalent and usually included *S. costatum*, *L. minimus*, *C. closterium*, *Thalassiosira* spp. and *Chaetoceros* spp. Dinoflagellates that were summer bloom producers included several *Gymnodinium* spp., *H. rotundata* and *P. minimum*. Other flagellates that were often abundant during the summer months included several *Cryptomonas* and *Pyramimonas* taxa.

The degree of summer floral development that continued into autumn varied considerably year to year and was influenced by conditions associated with water flow through the estuary and related residency time for algal development into the autumn months (Marshall and Alden, 1997; Marshall and Burchardt, 1998). In general, the early autumn (e.g. September) flora continued to mimic the summer composition before yielding to a more diatom dominant assemblage. This later composition was typically composed of many spring bloomers, *S. potamos* in tidal freshwater/oligohaline regions and *S. costatum*, *L. minimus* and *C. closterium* in the higher saline regions. This was another transitional period where dinoflagellate, cyanobacteria and chlorophyte development decreased into winter. These months represented the lowest concentrations of cyanobacteria, chlorophytes and dinoflagellates, with diatoms continuing as the dominant flora into the spring bloom. Ubiquitous throughout these seasons were the cryptophytes. Their presence and abundance varied seasonally along with other less prominent taxa. Many of these taxa were in low abundance with seasonal expressions of development that were often of short duration and not commonly present in all water samples.

Potential harmful species

Included among the flora in the Chesapeake Bay estuarine complex were 34 species that have previously been identified as harmful or toxin producers (Steidinger, 1993; Cronberg *et al.*, 2003; Fryxell and Hasle, 2003; Moestrup, 2004). These were the diatoms *Amphora coffeaeformis*, *Pseudo-nitzschia multiseries*, *Pseudo-nitzschia pseudodelicatissima*, *Pseudo-nitzschia pungens* and *Pseudo-nitzschia seriata*; the dinoflagellates *A. sanguinea*, *C. polykrikoides*, *Dinophysis acuminata*, *Dinophysis acuta*, *Dinophysis caudata*, *Dinophysis fortii*, *Dinophysis norvegica*, *K. micrum*, *Pfiesteria piscicida*, *Pfiesteria shumwayae* and *P. minimum* and the raphidophytes *Chattonella verruculosa*, *Chattonella subsalsa* and *Heterosigma akashiwo*. To date, none of these taxa has been associated with annual toxic events (Marshall, 1996); however, *P. piscicida* was linked to fish deaths and human illness in Maryland estuaries in 1997 by Grattan *et al.* (Grattan *et al.*, 1998). The presence alone of these potentially toxic species does not indicate they will produce toxins. Many of these taxa will have physiological strains that vary in their ability to produce toxins and/or the amount of cells necessary to produce toxic levels to fish, etc. (Gordon *et al.*, 2002). Also included in this list was an assortment of cyanobacteria, mainly present in the tidal fresh and oligohaline regions of the tidal tributaries to Chesapeake Bay. These included both colonial and filamentous taxa with the most common bloom producer *M. aeruginosa*. The others were *Anabaena affinis*, *Anabaena circinalis*, *Anabaena flos-aquae*, *Anabaena recta*, *Anabaena solitaria*, *Anabaena spiroides*, *Aphanizomenon flos-aquae*, *Aphanizomenon issatschenkoi*, *Microcystis firma*, *Microcystis viridis*, *Planktothrix agardhii*, *Planktothrix limnetica*, *Planktothrix limnetica* f. *acicularis* and *Snowella lacustris*. In addition, Marshall and Burchardt (Marshall and Burchardt, 2004a) noted significant long-term trends of increased abundance and biomass of cyanobacteria in Virginia tidal estuaries, and a major component was *M. aeruginosa* with blooms of this taxon common during the summer months. The majority of these potentially toxic species are cosmopolitan with their occurrence associated with favorable environmental conditions for development related to specific ranges of salinity, temperature and increased nutrient availability (Burkholder and Glasgow, 1997). Their life cycle stages may also include dormant or resting stages, with their appearance in the water column rare, as with *Pfiesteria* spp., with others as common bloom producers (e.g. *C. polykrikoides*, *P. minimum*, *Pseudo-nitzschia pungens*, *M. aeruginosa*). The toxic status for several of these species, and others, continues to be under review in an attempt to associate toxin production with a particular taxon and has often resulted in the toxicity of previously considered strains to be re-examined (Li *et al.*, 2003). Further investigations may certainly modify this list, regarding its expansion, or removal of some taxa as not being a serious toxic threat.

DISCUSSION

The phytoplankton composition and its more abundant seasonal flora are presented with a current listing of phytoplankton taxa within Chesapeake Bay and its tidal estuaries. The pattern of increasing dominance of centric diatoms over pennate diatoms identified in sediment core samples by Cooper and Brush (Cooper and Brush, 1991) is supported by the results of our associated studies. The dominant diatoms throughout the year were small centric species that were also the major

components of the seasonal pulses from spring through autumn. The most common taxa within this group were *S. costatum*, *S. potamos*, *C. choctawhatcheeana*, *L. minimus* and *Thalassiosira* spp. Those taxa in the Bay water studies between 1918 and 1922 remain the dominant flora in current studies. These were the diatoms *S. costatum*, *C. pelagica*, *D. fragilissimus* and the dinoflagellate *P. micans*. However, a major difference was the increased concentrations of the phytoplankton (e.g. diatoms, dinoflagellates) compared with those reported 8 decades ago (Cowles, 1930; Marshall, 1988; Marshall and Alden, 1993). Brush and Davis (Brush and Davis, 1984) refer to sediment core results that show an increased frequency of anoxic events from the pre-European settlement period of this region. These anoxic events occur annually in Chesapeake Bay and have been associated with the water column stratification, lack of reoxygenation of the deeper regions of the Bay and the decomposition of organic detritus from phytoplankton blooms (Officer *et al.*, 1984). Brush and Davis (Brush and Davis, 1984) also predicted that increased phosphorus loading within the Bay would favor increased cyanobacterial development over diatom growth. We have reported increasing seasonal trends for cyanobacteria abundance and biomass (plus those of several other phytoplankton categories) within Chesapeake Bay and its tidal tributaries (Marshall and Burchardt, 2004a; Marshall and Lane, 2005). Another association within the changing trophic status of the Bay estuary was the increased recognition of potentially toxic species in these waters. These taxa may enter the Bay through the discharge of ballast water from ships coming from regions where these species occur, or their entry may come directly from freshwater tributaries or neritic waters entering the Bay. Passage from coastal waters to the Bay's subpycnocline waters was the apparent source of an extended bloom of *D. acuminata* in several northern Bay tributaries in 2002 (Marshall *et al.*, 2002). The earlier trophic status within the Bay and its tributaries was likely less enriched and not conducive to the survival and development for many of these and other flora, but a changing and enriched trophic condition would favor many of these toxic taxa and their continued presence. Such nutrient changes would also influence the development of other nontoxic flora and contribute to a changing floral composition among the phytoplankton.

In conclusion, the results indicated that a diverse phytoplankton population is present within the Chesapeake Bay estuarine complex that is seasonally dominated by diatoms and contains seasonally mixed assemblages of riverine, estuarine and neritic species. A current and expanded list of phytoplankton flora from Chesapeake Bay and its tidal rivers has been identified listing 1454 taxa (Table I). Present floral comparisons made to diatoms reported in sediment cores and associated with the pre-European settlement in this region have indicated that the plankton composition of diatoms has continued to change and is dominated by centrales diatoms. Water column composition comparisons to the initial phytoplankton studies in the Bay ~80 years ago revealed that phytoplankton diversity and abundance of the dominant flora have greatly increased, and although many of the dominant taxa that predominated at that time are common today, other major categories of flora (e.g. cyanobacteria, dinoflagellates) are also seasonally abundant. These transitions in composition and increased abundance are likely associated with an increased and modified eutrophication status of the Bay and its tributaries.

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