Journal of Coastal Research	SI	57	59-65	Gloucester Point, Virginia	2009

Phytoplankton of the York River

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ABSTRACT

MARSHALL, H.G., 2009. Phytoplankton of the York River. *Journal of Coastal Research*, SI (57), 59-65.

The York River possesses a diverse phytoplankton community represented by a variety of algal species that includes both freshwater and estuarine flora. The mean annual monthly range of abundance is ca. 5-20 X 10^6 cells L^{-1} with an extended bi-modal pattern that begins with an early spring diatom peak (March) that declines into early summer. The development of a more diverse representation of taxa in the summer results in a secondary late summer-early fall peak. Diatoms are the dominant phytoplankton component throughout the entire estuary including a variety of pennate and centric species such as *Asterionella formosa* and *Aulacoseira granulata*. Dinoflagellates are more common and abundant in the lower segments of the York River where they have been associated with re-occurring and extensive "red tide" blooms. These include *Cochlodinium polykrikoides, Heterocapsa triquetra, Heterocapsa rotundata, Scrippsiella trochoidea*, and *Prorocentrum minimum*. Cynobacteria, commonly referred to as blue-green algae, include unicellular, colonial, and filamentous taxa that are predominantly freshwater species. Among the more common taxa are *Microcystis aeruginosa*, a potential bloom producer, *Merismopedia tenuissima, Oscillatoria* spp., *Dactylococcopsis* spp., *Chroococcus* spp. and *Synechococcus* spp. The cyanobacteria are generally considered a nuisance category that do not represent a favorable food resource, and are commonly associated with increased trophic status. Chlorophytes or green algae, including *Ankistrodesmus falcatus*, *Chlorella* spp., *Pediastrum duplex, Scenedesmus acuminatus* and *Scenedesmus dimorphus* are more common from spring to fall with lowest abundance in winter. Overall, the phytoplankton status in the York has been classified as poor/fair condition. Further studies are needed regarding interrelationships between the floral and faunal components of the plankton community and linkages to water quality and physical environmental factors in the system. In addition, continued observations regarding long-term trends in phytoplankton abundance and composition need to be followed with emphasis on any increasing presence of potentially harmful phytoplankton species.

ADDITIONAL INDEX WORDS: *Chesapeake Bay, productivity, biomass, chlorophyll*

INTRODUCTION

Phytoplankton are the microscopic plant communities present in water based habitats throughout the world. They are common components in ponds and lakes of various sizes, rivers, estuaries and the world oceans. Species within this category may vary from less than one micron to several mm in size, in addition to filamentous forms that are several cm in length. However, phytoplankton are most common as unicellular taxa, or as colonial species. Their significance is that they represent a major food source associated with numerous fauna in these aquatic habitats which they in turn are linked to other predators, including those leading to the higher trophic levels. Through the process of photosynthesis they are capable of harvesting solar energy in their transformation of basic substances in the water to multiply and represent a food and energy product for various animal species. In addition, a major bi-product of their photosynthesis is oxygen, which is released into the water as another essential commodity for biota in these habitats.

Phytoplankton development will be influenced by the availability of sunlight and specific nutrients in the water. However, an excess of these nutrients during favorable conditions for growth may result in a rapid increase in their abundance to produce an algal bloom. This condition is often so dense that due to the photosynthetic pigments in their cells, the blooms will be associated with a red or brown coloration in the water that is often referred to as a "red or mahogany tide." The environmental impact of these massive blooms may include a reduction or depletion of oxygen within these waters. Although these bloom producing algae normally include autotrophic oxygen producing species during daylight hours, with darkness and the cessation of photosynthesis, their continual respiratory demands often results in reduced oxygen levels in late evening hours, and may result in either fish kills, or general stress conditions among the fauna. The death of the massive numbers of bloom species and their accumulation in the sediment will subsequently involve their decomposition with associated oxygen uptake, also contributing to hypoxic or anoxic conditions in these waters. Fortunately, the bloom events are generally short-lived and due to their dissipation by river flow and tidal action, lower concentrations of these algae will eventually be re-established.

PHYTOPLANKTON COMPOSITION, ABUNDANCE, BIOMASS, PRODUCTIVITY

The York River possesses a diverse phytoplankton community represented by a variety of algal species that includes both freshwater and estuarine flora. The freshwater species come from the two major tributaries of the York River (Pamunkey River, Mattoponi River) and the streams and marshes bordering the York. A total of 231 taxa was reported for the Pamunkey River at a tidal freshwater site (Marshall and

Burchardt 2004a), with 254 species recorded within the York River (Appendix; Marshall, personal records). These species are well represented by a diverse assemblage of diatoms, chlorophytes, cyanobacteria, and cryptomonads, in addition to dinoflagellates, euglenophytes, and others (Appendix).

Many of the freshwater flora (ca. diatoms, chlorophytes, cyanobacteria) are abundant in the oligohaline regions, whereas, the lower reaches of the river remain dominated by estuarine diatoms and dinoflagellates (Marshall and Alden, 1990). This array of species will also change seasonally in the different regions of the river. There is a natural succession that begins with a spring flora dominated by several diatom species, followed by a mixed algal composition in summer and fall, with a reduced representation and abundance in winter. The representation of freshwater and estuarine flora in the York River will be influenced by river flow, tidal movement, and factors that impact extremes of these events, ca. spring rains, summer draught, periodic storms, etc. Haas *et al*. (1981) also addressed the influence of stratification and mixing to phytoplankton, with Sin *et al*. (2006) stressing the importance and control that abiotic conditions (e.g. resource limitation) have on the phytoplankton presence than biotic factors (predation). Marshall and Burchardt (2003; 2004a) in a study of the tidal freshwater Pamunkey stressed the importance of river flow to phytoplankton composition and productivity.

Since 1985, the composition and abundance of phytoplankton in the Pamunkey/York Rivers have been monitored in the Chesapeake Bay Monitoring Program. Productivity and autotrophic picoplankton analysis were subsequently added (e.g. Marshall and Alden, 1990; Marshall and Affronti, 1992; Marshall and Nesius, 1993; Marshall and Burchardt 2003, 2004a, b; 2005; Marshall *et al*. 2005b). Based on this data base the mean monthly phytoplankton abundance, total phytoplankton, biomass, chlorophyll a and productivity over this entire time period are given for station RET 4.3 in the York River (Figures 1-4).

The mean monthly phytoplankton concentrations (excluding the picoplankton) are given in Figure 1. These indicate an extended bi-modal pattern that begins with an early spring peak (March) that declines into summer. This is a period of transition from a major diatom development to a more diverse representation of taxa in summer that results in a late summer-early fall development. Lowest concentration will

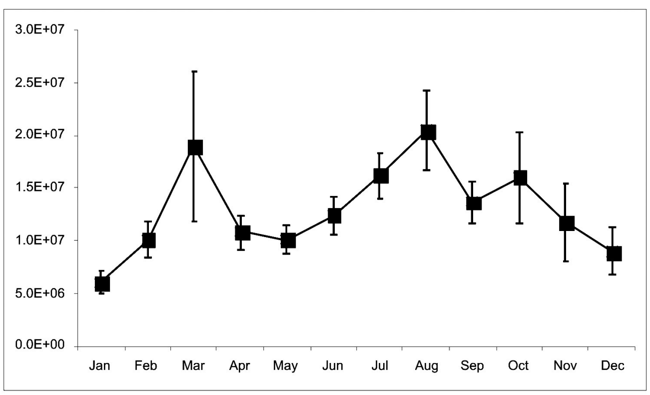

Figure 1. Mean monthly phytoplankton abundance (cells/L) 1985-2006, for station RET4.3 in the York River.

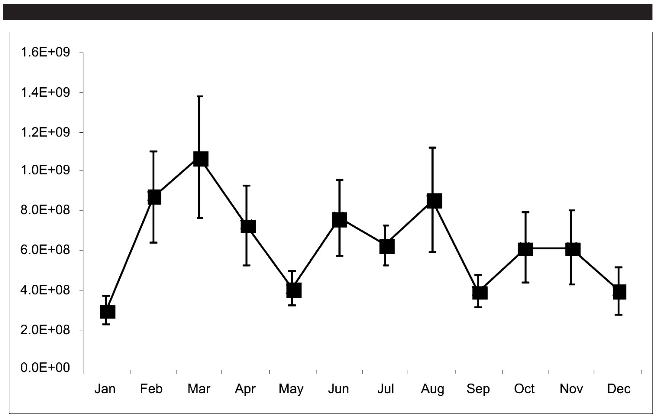

Figure 2. Mean monthly total phytoplankton biomass (pg C L-1) 1985-2006, for station RET4.3 in the York River.

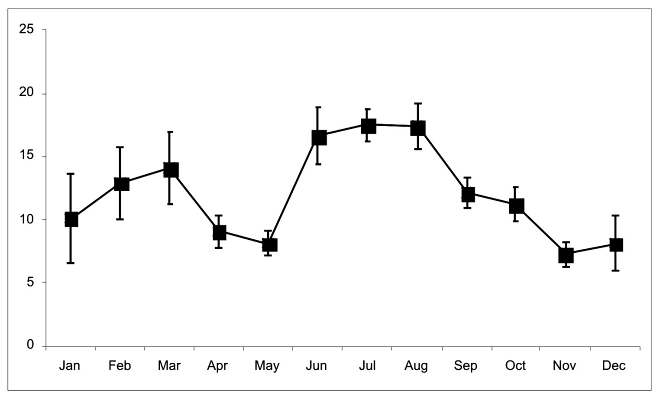

Figure 3. Mean monthly concentrations of Chlorophyll A (µg C L-1) 1985-2006 at station RET4.3 in the York River.

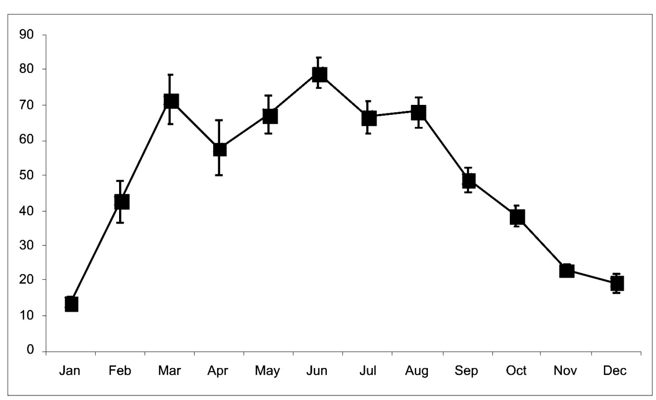

Figure 4. Mean monthly C14 productivity rates (mgC M3 h-1) 1989-2006, at station RET4.3 in the York River.

occur during mid-winter. The mean annual monthly range of abundance is ca. 5-20 X 10^6 cells L^{-1}.

Total phytoplankton biomass (which includes autotrophic picoplankton) is greatest during the spring diatom bloom, decreasing into early summer, followed by additional peaks in summer and autumn (Figure 2). The mean annual monthly range for algal biomass is ca. 2-10 X 10^8 pg C L^{-1}. Chlorophyll a concentrations will also vary over the year (Figure 3). However, they generally follow the phytoplankton concentrations with maximum amounts present during early spring and in summer, with mean monthly values ranging between 7-17 μg L^{-1}. Phytoplankton productivity is greater between March and August before decreasing to autumn and winter lows (Figure 7.4), with mean monthly rates from a January low to a June high of 13.7 and 79.1 9 mg C M^{-3} h^{-1} respectively.

DIATOMS

Diatoms are the dominant phytoplankton component throughout the York River in reference to their diversity, abundance, and biomass. They are represented by single cell, or short chain forming series of cells, that represent a major food source to the various faunal components in these waters. They are unique in having their cells enclosed within a cell wall of silica called a frustule, which is composed of two interlocking halves. The dominant freshwater diatoms in these waters include a variety of pennate *(Asterionella formosa)* and centric species (e.g. *Aulacoseira granulata, Aulacoseira distans, Cyclotella meneghiniana* (Figure 5), and *Skeletonema potamos*, among others) (Marshall and Alden, 1990; Marshall and Burchardt, 2005). In addition to these common plankton components in the water column, there are also a variety of taxa associated with the sediments and are composed of mainly pennate diatoms, which are also a major food source among the benthos. Many of these benthic species are regularly introduced into the water column during tidal mixing occasions. Diatoms will have a bi-modal spring/autumn pattern of development in the York River with a spring peak occurring in March with cell abundance ranging 8-18 X 10^6 cells L^{-1}. The winter low abundance is ca. 3 X 10^6 cells L^{-1}). Among the most dominant species are *S. potamos* upstream and *Skeletonema costatum* downstream. Diatom biomass values during the year will generally follow this same pattern as diatom abundance.

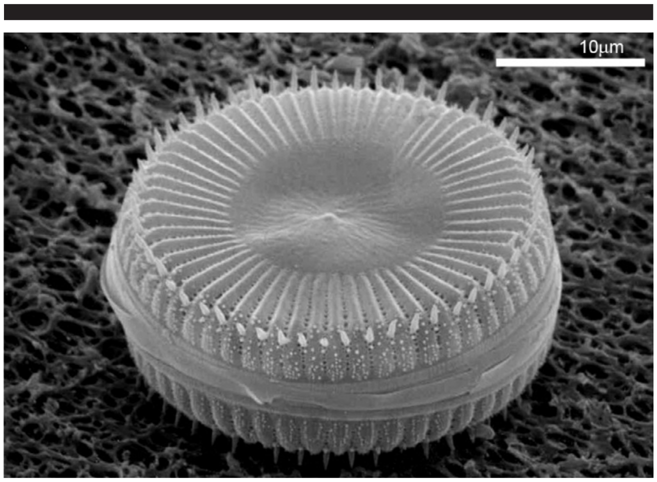

Figure 5. The diatom *Cyclotella meneghiniana*.

DINOFLAGELLATES

These are mainly unicellular species possessing flagella that allow movement in the water column. Many of these are autotrophic containing the necessary pigments to allow photosynthesis to occur, others lacking these pigments are heterotrophic and capable of engulfing small prey. There are others that are mixotrophic. The dinoflagellates are more common and abundant in the lower segments of the York River where they have been associated with re-occurring and extensive algal blooms. These include *Cochlodinium polykrikoides* (Figure 6), *Heterocapsa triquetra, Heterocapsa rotundata, Scrippsiella trochoidea,* and *Prorocentrum minimum* (Figure 7). Many of these taxa are associated with "red tide" events in these waters. The indigenous nature for many of these taxa is enhanced by their

Figure 6. *Cochlodinium polykrikoides*, a common bloom producing dinoflagellate in the lower regions of the York River.

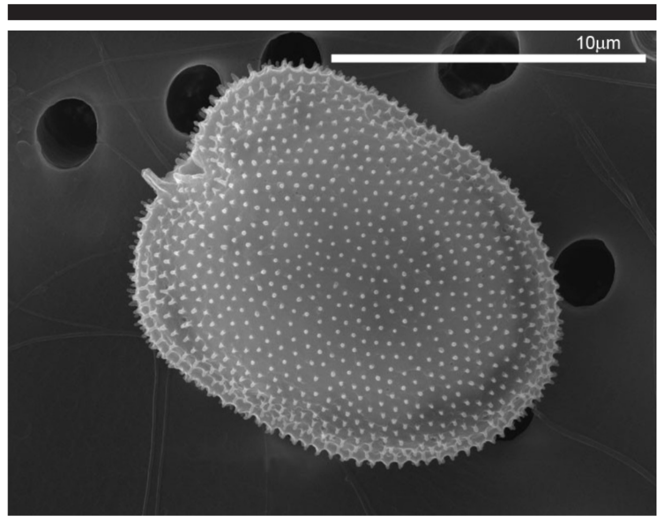

Figure 7. The common dinoflagellate *Prorocentrum minimum* in the York River.

formation of cysts, or "resting" stages, which sink to the sediment following their motile stage in the water column and subsequently represent the "seed" population that produce the motile cells of the next generation of these flora to take place annually. Many of the dinoflagellates will have maximum growth periods and corresponding biomass occurring in early to late spring and again in autumn at concentrations that are 1-2 X 10^6 cells L^{-1}. Also there are the sporadic dinoflagellate blooms common in the lower York. Most conspicuous of these is caused by *Cochlodinium polykrikoides*, which has produced extensive blooms annually (Mackierman, 1968; Zubkoff *et al.*, 1979; Marshall, 1994). In 1992 its abundance reached 10^3 cells mL^{-1} in the York and regions of the lower Chesapeake Bay, with a massive bloom in the lower York occurring in 2005 that lasted over several days at 10^3 cells mL^{-1} (Marshall *et al.*, 2006a).

CYANOBACTERIA

Species within this category represent a variety of forms, and are commonly referred to as blue-green algae. These include unicellular, colonial, and filamentous taxa that are predominantly freshwater species. In the York River these taxa are most common in the upper reaches of river, and in its two tributaries, with characteristically low abundance in the higher salinity regions of the river. Among the more common taxa in the York are *Microcystis aeruginosa* (Figure 8, a potential bloom producer), *Merismopedia tenuissima*, plus several *Oscillatoria* spp., plus *Dactylococcopsis* spp., and representative *Chroococcus* spp. and *Synechococcus* spp. The cyanobacteria are generally considered a nuisance category that do not represent a favorable food resource, and is commonly associated with increased trophic status. Their major development in the York occurs during summer and early autumn at ca. 3-8 X 10^6 cells L^{-1} before decreasing into winter months, with their total cell biomass representation following a similar pattern.

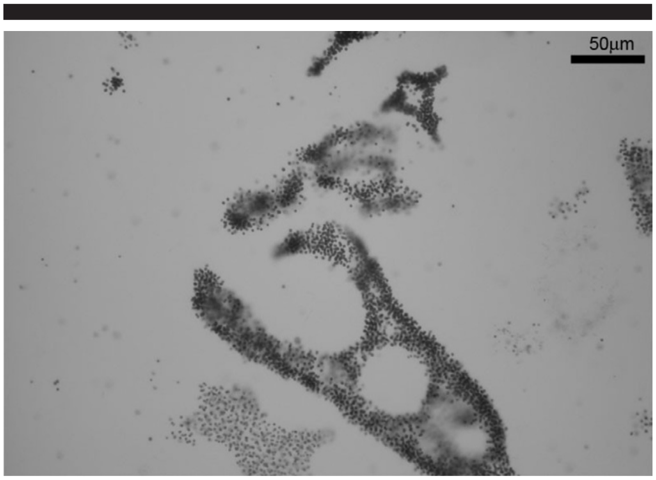

Figure 8. *Microcystis aeruginosa*, a colonial forming species of the cyanobacteria.

CHLOROPHYTES

These are common freshwater species, commonly known as green algae. Their high concentrations in the York River are more limited to the low salinity areas below the confluence of the Pamunkey and Mattoponi Rivers, but would increase in abundance downstream during high river flow. Their presence normally diminishes downstream. Common representation in the water column would be by *Ankistrodesmus falcatus, Chlorella* spp., *Pediastrum duplex, Scenedesmus acuminatus* and *Scenedesmus dimorphus*. Chlorophytes are more common from spring to fall with lowest abundance in winter. Their concentration levels are generally between 0.3-0.8 X 10^6 cells L^{-1} and usually these represent a small fraction of the algal biomass that would peak in summer.

AUTOTROPHIC PICOPLANKTON

This is a special phytoplankton category composed of cells less than 2 microns in size. The populations are composed of mainly single cell or colonial cyanobacteria, and to a much lesser representation by chlorophytes and other eukaryotes. Autotrophic picoplankton are ubiquitous throughout the year with their maximum development during the summer-early fall months with concentrations of ca. 2-4.5 X 10^8 cells L^{-1}. Their concentrations decline into autumn, with lowest levels during winter and spring. Their development during summer is a major contributor to the overall algal productivity, oxygen production, and food source for a variety of microorganisms.

OTHER CATEGORIES OF PHYTOPLANKTON

In addition to the more dominant flora mentioned above there are also a variety of background species that seasonally appear in lesser abundance and biomass, yet contribute to the overall photosynthetic activity and represent an additional food and oxygen source. The most common of these would be the cryptophytes, composed of a variety of motile single cell taxa present the entire year with mean monthly concentrations of ca. 1-3 X 10^6 cells L^{-1}, with peak concentrations during summer and autumn. These taxa include *Cryptomonas erosa* and *Rhodomonas minuta*. This group is a suitable food source for many of the heterotrophic dinoflagellates and zooplankton. Other algal categories are more frequently associated with the period following the spring diatom pulse and occur in summer and early autumn. For instance, the euglenophytes represent a category often showing pulses of significant size (3-4 X 10^4 cells L^{-1}), but are generally in low abundance. Upstream they include several *Euglena* spp., with *Eutreptia lanowii* more common downstream. *Trachelomonas*, and *Phacus* species are rare within the York. The same can be said of other eukaryotes that generally play a minor role in the phytoplankton dynamics in the river.

Among the different phytoplankton categories are also species that are considered harmful to other biota, or even be associated with human illness. Several are linked to toxin production, et al. related to anoxic or hypoxic conditions associated with bloom production (Marshall *et al.*, 2005). Examples of these potentially harmful species include the dinoflagellates *Akashiwo sanguinea, Cochlodinium polykrikoides, Dinophysis acuminata, Karlodinium micrum, Prorocentrum minimum, Pfiesteria piscicida, Pfiesteria shumwayae*; the diatom *Pseudo-nitzschia seriata*; the cyanobacteria *Microcystis aeruginosa*, among others (See Marshall *et al.*, 2005a for list of 34 taxa). Within the York River attention has recently been focused on increasing concentrations and any associated environmental impact related to blooms of the dinoflagellates *Cochlodinium polykrikoides, Karlodinium micrum,* and *Prorocentrum minimum*.

STATUS AND TRENDS

Using a 16-year database for stations in the Pamunkey/York River several significant long term phytoplankton trends have been identified in addition to several water quality variables (Marshall and Burchardt, 2004b). Increasing trends in total phytoplankton abundance and biomass were indicated along with similar increasing biomass trends for the diatoms, cyanobacteria, chlorophytes, and cryptomonads. There was a negative trend associated with the autotrophic picoplankton, with none indicated for the dinoflagellates. Of note, other trends included increasing TP concentrations, and decreasing TN:TP ratios (ca. 11.0). In this analysis there were also decreasing trends in Secchi readings matched with increasing levels of TSS.

A further appraisal of the York River phytoplankton habitats was included in the paper by Lacouture *et al*. (2006). They developed a phytoplankton index of biotic integrity based on a community structure protocol described by Buchanan et al. (2005), and using an 18-year data set coming from the Chesapeake Bay Phytoplankton Monitoring Program. This approach utilized a combination of nutrients (DIN, PO_4) and Secchi depth values to characterize the phytoplankton habitat conditions at sites in the Chesapeake Bay and several of its major tributaries within a variety of salinity ranges during spring and summer. A variety of phytoplankton metrics were chosen to provide a ranking for these locations (e.g. Poor, Fair, Good). In the characterization for the upper-river and lower river mouth sites in the York River, both received a spring status ranking of poor/fair, and in summer poor and poor/fair respectively. However, it should be noted that many of the sites in the Chesapeake Bay Monitoring Program included rankings of Poor and Poor/fair, with a Good ranking rare. A Poor (impaired) status was interpreted as having an excess of DIN or PO_4 levels and reduced water clarity that would be associated with the degree and composition of phytoplankton development at these locations. A Fair classification would represent an improved condition in one of these variables. Considering this classification, an increase in nutrient levels within the York would not be considered desirable for the environmental status in the York. Thus, although many of the phytoplankton trends are presently favorable, a continued increase in nutrient levels may easily end this pattern and produce a variety of less favorable species for food and oxygen production (including others that are potentially harmful) within the York River.

FUTURE RESEARCH NEEDS

Further studies are needed regarding interrelationships between the floral and faunal components of the plankton community and linkages to water quality and physical environmental factors within the various salinity regions and trophic levels in the system. In addition, continued observations regarding long-term trends in phytoplankton abundance and composition need to be followed with emphasis on any increasing presence of potentially harmful phytoplankton species. Each of these areas are linked to various important fin fish and shellfish resources utilized in the river and would be associated with their harvest and related socio-economic concerns.

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APPENDIX

York River Phytoplankton Species List

BACILLARIOPHYCEAE

Achnanthes sp.
Amphiprora alata
Amphiprora sp.
Amphora sp.
Asterionella formosa
Asterionella sp.
Asterionellopsis glacialis
Asterionellopsis karina
Aulacoseira distans
Aulacoseira granulata
Aulacoseira granulata var. *angustissima*
Aulacoseira islandica
Aulacoseira sp.
Bacillaria paxillifer
Bacteriastrum delicatulum
Biddulphia rhombus f. trigona
Cerataulina pelagica
Chaetoceros affinis
Chaetoceros compressus
Chaetoceros constrictum
Chaetoceros constrictus
Chaetoceros decipiens
Chaetoceros didymus var. *protuberans*
Chaetoceros neogracilis
Chaetoceros pendulus
Chaetoceros pseudocurvisetus
Chaetoceros socialis lauder
Chaetoceros sp.
Chaetoceros subtilis
Chaetocerus curvisetus
Cocconeis distans
Cocconeis sp.
Corethron sp.
Coscinodiscus centralis
Coscinodiscus concinnus
Coscinodiscus granii
Coscinodiscus oculus iridis
Coscinodiscus sp.
Cyclotella caspia
Cyclotella meneghiniana
Cyclotella spp.
Cyclotella striata
Cylindrotheca closterium
Cymbella sp.
Dactyliosolen fragilissimus
Delphineis surirella
Detonula pumila
Diatoma sp.
Diploneis sp.
Ditylum brightwellii
Eucampia zodiacus
Eunotia sp.
Fragilaria capucina
Fragilaria sp.
Gomphonema sp.
Grammatophora sp.
Guinardia delicatula
Guinardia flaccida
Gyrosigma balticum
Gyrosigma balticum silimis
Gyrosigma fasciola
Gyrosigma sp.
Hantzchia sp.
Hemiaulus hauckii
Hemiaulus membranaceus
Lauderia borealis
Leptocylindrus danicus
Leptocylindrus minimus
Licmophora sp.
Lithodesmium undulatum
Melosira jurgensii
Melosira moniliformis
Melosira nummuloides
Melosira sp.
Melosira varians
Meridion circulare
Navicula cuspidata var. *ambigua*
Navicula sp.
Nitzschia sp.
Odontella
Odontella mobiliensis
Odontella rhombus
Odontella sinensis
Paralia sulcata
Pinnularia sp.
Plagiogramma vanheurckii
Pleurosigma angulatum
Pleurosigma elongatum
Pleurosigma sp.
Proboscia alata
Proboscia alata gracillima
Pseudo-nitzschia pungens
Pseudo-nitzschia seriata
Psuedosolenia calcar-avis
Rhaphoneis amphiceros
Rhaphoneis sp.
Rhizosolenia imbricate
Rhizosolenia setigera
Rhizosolenia styliformis
Skeletonema costatum
Skeletonema potamos
Skeletonema sp.
Stauroneis sp.
Stephanopyxis palmeriana
Striatella sp.
Surirella ovalis
Surirella sp.
Synedra closterioides
Synedra sp.
Tabellaria sp.
Thalassionema nitzschioides
Thalassiosira anguste-lineata
Thalassiosira decipiens
Thalassiosira nordenskioeldii
Thalassiosira sp.
Thalassiothrix mediterranea
Tropidoneis lepidoptera

DINOPHYCEAE

Akashiwo sanguinea
Amphidinium acutissimum
Amphidinium crassum
Amphidinium extensum
Amphidinium sp.
Amphidinium sphenoides
Ceratium tripos
Cochlodinium brandtii
Cochlodinium polykrikoides

Cochlodinium sp.
Dinophysis acuminata
Dinophysis punctata
Dinophysis schroderi
Dinophysis sp.
Diplopsalis lenticula
Glenodinium sp.
Gonyaulax sp.
Gymnodinium danicans
Gymnodinium sp. <20 microns
Gymnodinium sp. >20 microns
Gymnodinium verruculosum
Gyrodinium fusiforme
Gyrodinium sp.
Heterocapsa rotundata
Heterocapsa triquetra
Karlodinium micrum
Katodinium asymmetricum
Noctiluca scintillans
Oblea rotunda
Oxyrrhis marina
Oxytoxum milneri
Rhizosolenia sp.
Peridinium sp.
Pfiesteria piscicida
Pfiesteria shumwayae
Polykrikos kofoidii
Prorocentrum aporum
Prorocentrum dentatum
Prorocentrum gracile
Prorocentrum micans
Prorocentrum minimum
Prorocentrum sp.
Protoperidinium breve
Protoperidinium brevipes
Protoperidinium conicum
Protoperidinium depressum
Protoperidinium divergens
Protoperidinium globulum
Protoperidinium granii
Protoperidinium minutum
Protoperidinium sp.
Scrippsiella trochoidea

PRYMNESIOPHYCEAE
Rhabdosphaera hispida

RAPHIDOPHYCEAE
Chattonella verruculosa

SILICOFLAGELLATES
Dictyocha fibula
Ebria tripartita

CYANOBACTERIA
Anabaena sp.
Aphanocapsa sp.
Aphanothece sp.
Calothrix sp.
Chroococcus limneticus
Chroococcus sp.
Coelosphaerium sp.
Dactylococcopsis raphidioides
Dactylococcopsis sp.
Gomphosphaeria aponina
Merismopedia elegans
Merismopedia punctata
Merismopedia sp.
Merismopedia tenuissima
Microcoleus sp.
Microcystis aeruginosa
Microcystis incerta
Microcystis sp.
Nostoc sp.
Oscillatoria sp.
Phormidium sp.
Spirulina sp.

EUGLENOPHYTA
Euglena acus
Euglena sp.
Eutreptia lanowii
Eutreptia sp.
Eutreptia viridis
Phacus spp.
Trachelomonas sp.

CHLOROPHYCEAE
Actinastrum hantzschii
Ankistrodesmus falcatus
Ankistrodesmus falcatus var. *mirabilis*
Ankistrodesmus sp.
Botryococcus sp.
Chlamydomonas sp.
Chlorella sp.
Closteriopsis longissima
Closterium sp.
Cosmarium sp.
Crucigenia crucifera
Crucigenia fenestrata
Crucigenia quadrata
Crucigenia sp.
Crucigenia tetrapedia
Desmidium sp.
Dictyosphaerium pulchellum
Dictyosphaerium sp.
Elakatothrix gelatinosa
Euastrum sp.
Kirchneriella sp.
Micractinium pusillum
Micractinium sp.
*Oocystis*sp.
Pandorina sp.
Pediastrum duplex
Quadrigula lacustris
Quadrigula sp.
Scenedesmus acuminatus
Scenedesmus abundans
Scenedesmus bijuga
Scenedesmus dimorphus
Scenedesmus quadricauda
Scenedesmus sp.
Schroederia setigera
Selenastrum minutum
Selenastrum sp.
Staurastrum americanum
Staurastrum sp.
Tetraedron regulare
Tetraedron sp.
Treubaria setigerum
Ulothrix sp.

CRYPTOPHYCEAE
Cryptomonas erosa
Cryptomonas sp.
Rhodomonas minuta

CHRYSOPHYCEAE
Apedinella radians
Calycomonas ovalis
Dinobryon cylindricum
Dinobryon sertularia
Dinobryon sp.
Synura sp.
Synura uvella

PRASINOPHYCEAE
Pyramimonas micron
Pyramimonas sp.