

**Baseline Characterization of Phytoplankton and Harmful
Algal Blooms in Barnegat Bay-Little Egg Harbor, New Jersey
(Year One)**

FINAL REPORT

Revised

Prepared for

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TABLE OF CONTENTS

	Page
LIST OF TABLES	II
LIST OF FIGURES	III
EXECUTIVE SUMMARY	V
INTRODUCTION.....	1
BACKGROUND.....	1
OBJECTIVES OF STUDY.....	3
STUDY AREA	3
FIELD AND LABORATORY METHODS	4
SAMPLING	4
PHYTOPLANKTON WHOLE-COMMUNITY COUNTS.....	5
RESULTS AND DISCUSSION	7
HYDROLOGICAL AND CHEMICAL CONDITIONS.....	7
SPECIES COMPOSITION.....	8
BLOOM PATTERNS AND SPECIES SUCCESSION	9
COMPARISON WITH PREVIOUS STUDIES	13
HARMFUL ALGAL BLOOMS AND HAB SPECIES	15
<i>Brown tide Aureococcus anophagefferens</i>	15
<i>Prorocentrum minimum</i>	16
<i>Scropsiella trochoidea</i>	17
<i>Chaetoceros spp.</i>	17
<i>Pseudo-nitzschia spp.</i>	17
<i>Akashiwo sanguinea</i>	18
BIOVOLUME CALCULATION AND CARBON BIOMASS ESTIMATION.....	18
IMAGE DOCUMENTATION.....	18
SUMMARY	19
FURTHER STUDIES.....	21
ACKNOWLEDGEMENTS	22
REFERENCES.....	23
TABLES.....	27
FIGURES.....	43
APPENDICES.....	72

LIST OF TABLES

Table 1: List of sites for phytoplankton collection in Barnegat Bay-Little Egg Harbor (August 2011-September 2012).

Table 2: Summary of nutrients in surface water during phytoplankton collections from August 2011 to September 2012. Re-organized from NJDEP water quality data from <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>.

Table 3: List of phytoplankton species in Barnegat Bay-Little Egg Harbor estuary from August 2011 to September 2012.

Table 4: Abundant species of phytoplankton at site BB10, August 2011- September 2012.

Table 5: *Aureococcus anophagefferens* (AA) detected from sites BB09, BB10 and BB14, using polyclonal antibody method

Table 6: Summary of main HAB species observed in BB-LEH from August 2011 to September 2012.

Table 7: Biovolume measurements of dominant/abundant phytoplankton in Barnegat Bay-Little Egg Harbor, from August 2011 to September 2012.

LIST OF FIGURES

Fig. 1. Site locations of phytoplankton collections in 2011-2012.

Fig. 2-4. Change of water temperature (Fig. 2), salinity (Fig. 3) and turbidity (Fig. 4) at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring,

<http://www.nj.gov/dep/barneгатbay/bbmapviewer.htm>

Fig. 5. Change of chlorophyll *a* at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring,

<http://www.nj.gov/dep/barneгатbay/bbmapviewer.htm>

Fig. 6. Abundance and seasonal changes of some dominant species at site BB01 from August 2011 to September 2012.

Fig. 7. Abundance and seasonal changes of some dominant species at site BB02 from August 2011 to September 2012.

Fig. 8. Abundance and seasonal changes of some dominant species at site BB04 (BB04a) from August 2011 to September 2012.

Fig. 9. Abundance and seasonal changes of some dominant species at site BB05 (BB05a) from August 2011 to September 2012.

Fig. 10. Abundance and seasonal changes of some dominant species at site BB07 (BB07a) from August 2011 to September 2012.

Fig. 11. Abundance and seasonal changes of some dominant species at site BB09 from August 2011 to September 2012.

Fig. 12. Abundance and seasonal changes of some dominant species at site BB12 from August 2011 to September 2012.

Fig. 13. Abundance and seasonal changes of some dominant species at site BB14 from August 2011 to September 2012.

Fig. 14. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB01 from August 2011 to September 2012.

Fig. 15. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB02 from August 2011 to September 2012.

Fig. 16. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB04 (BB04a) from August 2011 to September 2012.

Fig. 17. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB05 (BB05a) from August 2011 to September 2012.

Fig. 18. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB07 (BB07a) from August 2011 to September 2012.

Fig. 19. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB09 from August 2011 to September 2012.

Fig. 20. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB12 from August 2011 to September 2012.

Fig. 21. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB14 from August 2011 to September 2012.

EXECUTIVE SUMMARY

We carried out a two-year survey on the phytoplankton community in Barnegat Bay-Little Egg Harbor (BB-LEH) estuary in New Jersey through coordination with New Jersey Department of Environmental Protection (NJDEP)'s Bureau of Marine Monitoring during 2011-2013. The study aims to characterize species composition and spatial and temporal trends in the BB-LEH phytoplankton community, and to document bloom patterns and dominant species succession as well as Harmful Algal Bloom (HABs) species over time. This report presents the major results from year one of the study, including species composition, seasonal changes of dominant/abundant species, and species succession at the study sites, as well as biovolume calculation and carbon biomass estimation based on cell density. Several major HAB species and their occurrences and abundance are documented. We compare present results with those from previous surveys.

During the year-one study, 151 monthly (October to March) and biweekly (from April to September) samples were collected and analyzed from 9 sites. We recorded 135 taxa; 53% were diatoms and 18% were dinoflagellates. Most of the common species range in size from 2 to 20 μm (nanoplankton), and a majority fall within 2 to 10 μm . The major algal groups and most of the species in the current study are comparable with previous studies. However, several abundant/dominant species with size range of <1 to 5(6) μm were, to the best of our knowledge, not formerly recorded. Further work on the taxonomy of these species is essential, especially in consideration of their abundance/dominance in the phytoplankton community and possible ecological significance.

Pronounced seasonal changes in phytoplankton species composition and succession were detected at most sites. We observed the dominance of picoplankton, as pico-cocoids in the present study, in summer from June through September, which is consistent with previous studies. The species composition of picoplankton is also comparable to previous studies. The difference in species succession between northern and southern sites was noticeable. Phytoplankton in southern Barnegat Bay and Little Egg Harbor was dominated mainly by diatoms, whereas phytoplankton assemblages in northern Barnegat Bay were dominated by different groups of algae. The species succession in the north

proceeded, from winter to fall, from dinoflagellate *Prorocentrum minimum* with some larger and chain-forming diatoms → small Chlorophycean flagellate → spine-forming *Chaetoceros* → coccoidal picoplankton and small centric diatoms.

Several dominant/ abundant species, including *Chlamydomonas* sp. 'c', *Chaetoceros* cf. *tenuissimus*, *Phaeodactylum* ? *tricornatum* and *Skeletonema menzelii*, showed more spatially specific north-to-south distribution patterns compared to most other abundant species. The spatial differences in the species are likely due to their salinity tolerance. Salinity in north ranged mostly between 16 to 24 ppt, while in south it fluctuated from 24 to 30 ppt (Fig. 3). The promotion of blooms or dominance of certain species may also be affected by nutrient availability, grazing and other factors. Studies on nutrient-phytoplankton-zooplankton interrelationships in BB-LEH, to our knowledge, are scarce. More studies specific to the BB-LEH ecosystem are required in order to better understand nutrient effects, phytoplankton community change and related food web alteration in the system.

We detected a low density of brown tide in several samples from BB09 and BB12 and BB14 in summer 2012. Fortunately, severe intensive brown tide blooms were not observed in 2012. Phytoplankton sample collection in 2011 started in August, and no brown tide bloom was detected from our 2011 samples. However, we have detected several other HAB species including *Prorocentrum* species, *Chaetoceros* species, *Scropsiella trochoidea*, *Akashiwo sanguinea*, and several *Pseudo-nitzschia* species. The bloom levels of *P. minimum* and a small *Chaetoceros* species were detected in northern Barnegat Bay. Also, *Pseudo-nitzschia pungens* was once observed at high level (10^6 cells L^{-1}) at BB14. The reoccurrences of these species, and their toxicity and/or negative impacts on other organisms in the food web in BB-LEH is unknown, and needs to be further investigated.

Further detailed comparison with phytoplankton data from previous studies can be difficult, and even more so for BB-LEH, because 1) different methodologies were used by different laboratories in previous studies; and 2) most of the abundant or dominant species are small, within size range of 1-15 μm . This is especially true for picoplankton, within which several size and morphologically similar species often coexist. More

taxonomic work is required to better understand the composition of small phytoplankton. In addition, the Barnegat Bay ecosystem may be changing due to the rapidly developing watershed and pollution control efforts in the past decade. This is especially the case in northern Barnegat Bay. Because of its shallowness and long residence time, its phytoplankton community may be more susceptible to alteration following changes of river discharge, nutrients and any hydrological modification. Carter (2001), using GIS trend analysis, identified the northern part of Barnegat Bay as a common problem area based on four indicators (population, fecal coliform level, non-point N and P input). The massive bloom of small *Chaetoceros* species (tentatively *Ch. cf. tenuissimus*) in spring and high abundance of *Prorocentrum minimum* in winter in northern Barnegat Bay is worrisome due to their harmful characteristics. Further monitoring and research studies should be done to understand and predict the development of these harmful species and their possible impacts on the ecosystem.

INTRODUCTION

Background

Barnegat Bay has progressed from a moderately eutrophic (Seitzinger and Pilling 1993) to a highly eutrophic coastal system (Kennish et al. 2007) during the past decades. The change has been mainly attributed to human activities in the watershed area including population growth, industrial operations, agriculture, recreational pursuits, and domestic water uses which are related to nutrient enrichment in the Bay, especially non-point source nitrogen and phosphorus loadings. In estuarine and coastal systems like Barnegat Bay-Little Egg Harbor (BB-LEH), phytoplankton species composition, as well as the succession of bloom patterns is directly linked to changes of external nutrient loading. These changes in phytoplankton components can often have significant effects on the organisms at higher trophic levels in the food web. For instance, fish kills and/or reduction of some important fishery resources are often linked to, directly or indirectly, some specific algae, especially harmful algal blooms. The complex interactions between anthropogenic nutrient loadings, phytoplankton response and food web alteration are not well known in many coastal systems, particularly in terms of long-term changes (Livingston 2007).

There have been limited investigations of phytoplankton in BB-LEH in the last century (Olsen and Mahoney 2001, and references therein). Martin (1929) focused on larger forms of phytoplankton, particularly dinoflagellates. Studies by Mountford (1967, 1971) were conducted mainly in northern and central Barnegat Bay. In 1987, NJDEP conducted a survey throughout BB-LEH on the phytoplankton community. Characteristic picoplankton ('ultraplankton') blooms in summer have been documented from those surveys (Mountford 2013, Olsen and Mahoney 2001). Although brown tide blooms probably occurred earlier than 1995, the first confirmed 'brown tide' bloom in BB-LEH was in 1995; blooms were detected in 1997 and 1999. An intensive survey was carried out by the National Marine Fisheries Service during 1997-1998 shortly after the 1997 brown tide occurrence. In addition, a phytoplankton monitoring program along the NJ coastline has been launched, sampling primarily in summer months (June-August) with 6 sites in the BB-LEH system (<http://www.state.nj.us/dep/bmw/phytoplankton.htm>). The

monitoring is designed specifically to detect brown tide occurrences, and other harmful algal blooms (HABs) to help ensure shellfish are safe for human consumption. Recently, a series of studies related to brown tide, *Aureococcus anophagefferens*, have been carried out in BB-LEH (Mahoney et al. 2006, Pecchioli et al. 2006) due to severe detrimental effects on bivalves and eelgrass (Bricelj and Lonsdale 1997). While the above-mentioned monitoring and investigations focus on HABs, surveys about the community structure of phytoplankton in BB-LEH are lacking in recent years. While chlorophyll measurements give the level of total biomass in the water column, it is important to know the species composition of phytoplankton assemblages and their temporal and spatial distributions to better understand the dynamics of biological processes in the BB-LEH system. There are several reasons. One, phytoplankton in BB-LEH appears very diverse and species successions and bloom patterns are dynamic (Mountford 2013, Olsen and Mahoney 2001). However, it has been more than a decade since the last intensive and thorough phytoplankton investigation (Olsen & Mahoney 2001). An investigation of phytoplankton is necessary and important for up-to-date water quality assessment in the BB-LEH. Two, while point source nutrient inputs have been eliminated from the BB-LEH since 1980, non-point nutrient loading, especially nitrogen, has accelerated due to population growth and watershed development (Kennish et al. 2007). Knowing how the ongoing changes in concentration, ratios and composition of external nutrient inputs have affected phytoplankton assemblages and bloom patterns is essential for water quality management and restoration in this estuarine system. Third, brown tide, *A. anophagefferens*, contains a large number of proteins involved in light harvesting and organic matter utilization, as well as metal and selenium requiring enzymes that allow the alga to outcompete other phytoplankton species in shallow eutrophic coastal regions (Gobler et al. 2011). However, the factors triggering brown tides and their interactions with other algae, especially other pico-plankton during summer blooms in BB-LEH system, are still not fully understood (Gobler et al. 2005, Pecchioli et al. 2006).

We carried out a two-year survey on the phytoplankton community in BB-LEH estuary in coordination with NJDEP Water Quality Monitoring in 2011-2013. This report presents the major results from year-one study, which includes seasonal changes of species composition, bloom patterns and dominant species successions from 9 study sites in BB-

LEH. Cell biovolume and carbon biomass estimation was calculated based on cell density data from 8 of the 9 sites. The occurrence and abundance of several HAB species are documented. We further compare present results with those from previous surveys.

Objectives of Study

This study aims to characterize species composition and spatial and temporal trends in the BB-LEH phytoplankton community, and to document bloom patterns and dominant species successions over time. In the year-one study, monthly and biweekly samples were collected from 9 study sites in BB-LEH from August 2011 to September 2012.

Quantitative analysis was performed on every analyzable sample. Dominant species were imaged during sample analysis. In addition, we calculated biovolume biomass based on species abundance and biovolume measurements. We compared year-one results with those from previous surveys reported in the literature. The objective of the study is to provide baseline information on the phytoplankton community in BB-LEH to assist current water quality assessment of the Bay system.

Study Area

The Barnegat Bay-Little Egg Harbor Estuary is a long and shallow lagoon-type water system located along the central New Jersey coastline (Fig.1). The system is approximately 70 km long, extending from Point Pleasant south to Little Egg Inlet. It is 2-6 km wide, with total surface area of 280 km² and average depth of ~1.5 m. The BB-LEH system is composed of three shallow bays: Barnegat Bay in the north, Manahawkin Bay and Little Egg Harbor in the south. The dominant exchange of bay water with the coastal ocean water is through a permanent breach-way at Barnegat Bay Inlet. Water also exchanges through the Point Pleasant Canal to the north and Little Egg Inlet to the south. Water residence time for the entire BB-LEH is estimated to be up to 74 days in summer, longer at the north end of the Bay (Guo et al. 2004). The major freshwater flows into BB-LEH are through Toms River, the Metedeconk River and Cedar Creek. The Barnegat Bay watershed represents 21% of the total land area in the Atlantic Coastal Drainage Basin. About one third of the watershed is developed with extensive areas of urban and suburban land-use. Non-point source nutrients, approximately 93% of phosphorus and

88% of nitrogen, are from urban land cover (Carter 2001). In general, there is a north-to-south gradient of decreasing developed watershed area and associated nitrogen loading. Toms River and Metedeconk River basins account for >60% of nitrogen loading from surface water discharge (Wienben and Baker 2009). Overall, the system is very susceptible to eutrophication due to relative low freshwater input, poor flushing and highly developed watershed areas.

In addition to tidal exchanges, winds also play a significant role in circulation. Since the BB-LEH is overall a shallow system, the water column is generally well-mixed, although two-layered circulation may exist in some deeper areas. Turbidity in BB-LEH varies seasonally with generally lower light penetration in summer (< 1 m, mean Secchi disk depths) compared to winter, and spatially higher turbidity in the north than the south (Seitzinger et al. 2001). Historically, organic nitrogen has been the dominant form of N in the water column with the highest concentration in summer. Dissolved inorganic nitrogen is generally low, about ten times lower than organic nitrogen. Inorganic nutrient concentrations are generally low in summer and higher during the late fall and winter (Seitzinger and Styles 1999). In addition, data collected by NJDEP shows significant amount of total phosphorus (TP) in BB-LEH, especially in the southern area. Recent assessment of eutrophication by Kennish and Fertig (2013) shows that TP condition in BB-LEH fell from Poor to Highly degraded in the period of 2004 to 2010. Chlorophyll *a* concentration in the Bay has varied from <5 $\mu\text{g l}^{-1}$ to >30 $\mu\text{g l}^{-1}$ averaging about 10 $\mu\text{g l}^{-1}$, generally highest in summer, sometimes spring, and lower in fall and winter (Mountford 2013, Olsen 1989). Annual phytoplankton production was estimated about 480 $\text{g C m}^{-2} \text{y}^{-1}$, similar in magnitude to values from other lagoon-type estuaries (Seitzinger et al. 2001).

FIELD AND LABORATORY METHODS

Sampling

Nine sites were selected for phytoplankton community analysis. The sites were coordinated with some of the existing sites of the NJDEP water quality monitoring in BB-LEH, which started in June 2011. Most of the sites are located in the middle sector of

the embayment, away from shorelines. The sites included six buoy stations BB02, BB05, BB07, BB09, BB12 and BB14 from the NJDEP Water Quality Monitoring program (NJDEP WQ-QAPP, 2011) (see Table 1 and Fig. 1 for the location of the phytoplankton sites). BB01 is located at the northernmost end of Barnegat Bay, just south of the Mantoloking Bridge and a USGS monitoring site (USGS01408168). BB04 is located near the mouth of Toms River. Phytoplankton samples collection from the above-mentioned sites started from August 2011 to September 2012. BB10 was added later to coordinate with the Hard Clam Study, therefore only a few samples were analyzed (Table 4). Starting in late May of 2012, sampling sites BB04, BB05 and BB07 were shifted to BB04a, BB05a and BB07a as indicated in Fig. 1 and Table 1. The seasonal data presented in this report, however, are from both before and after the shift. In year one, 151 samples were collected from these 9 sites and analyzed quantitatively for phytoplankton species composition.

Phytoplankton sample collections were synchronized with NJDEP water quality grab samplings. Approximately two-liters of surface water (<0.5 m) were collected monthly from August 2011 through March 2012, and biweekly from April through September 2012. The samples were preserved with 50% glutaraldehyde to a final concentration of 0.5% (v/v). Samples were kept dark and cool (~ 4°C) during transportation and prior to analysis. For each sample, three different processes were performed, 1) about 150-250 ml of sample water was dispensed for size-fractionated filtration and whole-community microscopic analysis; 2) one-liter of sample water was settled for further processing for diatom analysis when necessary; 3) about 200-500 ml of water, depending on the biomass, was settled to concentrate to about 20 ml for qualitative and light microscopic observation, if necessary, and for archive purposes. The remnants from 1) were also kept for archive.

Phytoplankton Whole-Community Counts

Phytoplankton samples were size-fractionated by filtering through 0.2 μm , 3 μm and 8 μm pore-size filters. The latter two fractions were stained with 0.03% proflavine hemisulfate. The 0.2 to 3 μm fraction was counted immediately after filtration. The >8 μm fraction was frozen and counted later. Algal identification and enumeration, including

soft-algae and diatoms, were done under an epifluorescence microscope (Leica DM L) with blue and green excitation lights and transmitted light. For 0.2 and 3 μm pore-size filters, observations were done under $\times 1000$ magnification. For each filter, at least 5 random fields were counted or until at least 100 cells were counted. If the filter was very sparse, then 50 random fields were counted before stopping. For 8 μm pore-size filters, each filter was observed under three magnifications: First, under $\times 1000$ magnification for phytoplankton $< 20 \mu\text{m}$ with the same counting strategy in terms of finishing point; second, under $\times 400$ magnification for larger ($> 20 \mu\text{m}$) phytoplankton with a maximum of 25 random fields when it was sparse; Third, under $\times 100$ magnification to catch some large organisms, which might not have been able to be counted under higher magnifications due to either their large size or sparse density. The method allowed us to be able to examine small size phytoplankton ($< 20 \mu\text{m}$) under higher magnification ($\times 1000$) compared to other methods, e.g. using Palmer-Maloney and/or Sedgewick-Rafter counting cells. The blue and green excitation helps us to differentiate groups of algae when stained with dyes (Dortch et al. 1997, Ren et al. 2009). For samples with high abundance and diversity of diatoms, diatom slides were made. Diatoms were analyzed to get the percentage of dominant diatoms, especially the small centric diatoms. Phytoplankton species were identified to the lowest taxonomic level possible. In addition, each common taxon (5% of total cell counts) was documented with images. Biovolumes of common taxa were calculated based on microscope measurements of dimensions and geometric models of phytoplankton (Hillebrand et al. 1999, Olenina et al. 2006).

For brown tide, *Aureococcus anophagefferens*, identification is challenging with regular light or fluorescence microscopes because of its small size and lack of features that distinguish it from other similar sized plankton. The immunofluorescence method is generally considered better for this species (Anderson et al. 1993). In Year-one of the study, we used brown tide culture to test the method of using the polyclonal labeling technique and fluorescence microscopic observation. We used the procedure obtained from the Woods Hole Oceanographic Institute (WHOI) with slight modification from its original publication (Anderson and Kulis 1989).

RESULTS AND DISCUSSION

Hydrological and Chemical Conditions

Water quality monitoring data for the 2011-2012 phytoplankton collection season were downloaded from a NJDEP website,

(<http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>). Water temperature, salinity (ppt), turbidity (NTU), and chlorophyll *a* for the nine sites are illustrated in Fig. 2-5.

Nutrient (N, P and Si) data are briefly summarized in Table 2.

There was little difference in water temperature among the nine sites (Fig. 2). The lowest temperature was detected in January- February and the highest in July-August. Salinity did not show much seasonal variation at the same site, but the differences among sites was prominent. In general, salinity was lower at northern sites compared to the southern ones (Fig. 3). Salinity at BB04 was the lowest among all sites and resulted from the freshwater input from Toms River. The overall trends are consistent with previous data (Kennish 2001). The change of turbidity may reflect both organic biomass and inorganic particulate matter in the water column. Turbidity at the northern sites showed more seasonal variations, coincident with chlorophyll *a*, indicating the dominance of phytoplankton biomass as suspended particulate matter in northern Barnegat Bay (Fig. 4). Turbidity at southern sites in Little Egg Harbor showed more fluctuations during the year, and did not correlate well with the change of chlorophyll *a* (Fig. 5), suggesting a more prominent role of physical processes, such as tidal exchange, currents and circulation in the change of suspended particulate matter.

The ranges of total nitrogen (TN) and total phosphorus (TP) were similar among most sites (Table 2). In general, values of TN were higher in the northern area (BB01 to BB07a), which is coincident with the major nitrogen loading from the rivers (Metedeconk River, Toms River and Cedar Creek), all in the north. Dissolved nitrogen (DN, inorganic + organic) accounted for at least 50%, and often >90%, of TN. Dissolved organic nitrogen (DON) was the dominant N form in DN. On the contrary, values of TP were generally lower at the northern sites than those in the south (BB09 to BB14). The percentage of dissolved phosphorus (DP) as a component of TP was lower at northern sites compared to the southern ones. Data up to March 2012 showed lower total silica

(TSi) and a higher percentage of silicate (inorganic form) in the north, suggesting less silicate utilization or diatom growth at northern sites compared to southern sites (BB09 to BB14).

Species Composition

A total of 135 taxa were recorded in the Year One study (Table 3). 21 taxa were common species observed frequently in several samples, or were abundant in at least one sample (Table 3 in bold). Most common species belong to the following five major groups: diatoms (Bacillariophyceae), dinoflatellates (Dinophyceae), cryptophytes (Cryptophyceae), chlorophytes (Chlorophyceae), and chrysophytes (Chrysophyceae). Diatoms comprised the largest number of species, 72, or 53% of the total, followed by dinoflagellates with 24, or 18% of the total. These two classes contribute most of the larger forms of phytoplankton in BB-LEH. Several chain-forming diatoms, including *Skeletonema costatum*, *Cerataulina pelagica*, *Asterionellopsis glacialis* and *Leptocylindrus minimus*, were found from most sites, but were more often abundant in southern sites (BB09, 10, 12 and 14). Some species, e.g. *S. costatum*, became dominant in winter and August. Some diatom species, large in dimension, were also frequently observed, including *Rhizosolenia imbricata*, *Lithodesmium undulatum*, *Guinardia flaccida*, and *Helicotheca tamesis*. In addition, *Coscinodiscus concinnus* and *C. granii* var. *major* were also found frequently. Dinoflagellates, including *Akashiwo sanguinea* (formerly *Gymnodinium nelsonii*, *G. splendens*), *Ceratium lineatum* and *Gymnodinium fusiforme* were often present. Most of these large species were recorded at relatively low cell density ($10^4 \sim 10^5 \text{ l}^{-1}$); their contribution to overall biomass, however, should not be neglected.

Most of the common species range in size from 2 to 20 μm (nanoplankton), and a majority fall within 2 to 10 μm . These include several diatoms, such as *Chaetoceros* cf. *tenuissimus*, *Cylotella choctawhatcheeana* and *Thalassiosira proschikinae*. The length of apical axis or valve diameters of these species can be as small as 3 to 5 μm , and they were found seasonally abundant and sometimes dominant during 2011-2012 (Fig. 6 to 13). In addition, *Skeletonema menzeli*, abundant in Little-Egg Harbor in summer (August-September), possesses valve diameter of 5 –7 μm . These species may appear

oval or round under the microscope when seen in valve view. Another group within the size range of nanoplankton are phytoflagellates. Phytoflagellates are distributed in several classes, including Cryptophyceae, Prasinophyceae, Chrysophyceae and Chlorophyceae (Table 3). In addition, two commonly seen dinoflagellates, *Gyrodinium flagellare* and *G. estuariale*, are generally < 20 µm. *Gyrodinium flagellare* sometimes are only about 8 ~ 9 µm in length.

In smaller size range of ~ 2 µm, in addition to the well-documented brown tide alga, *Aureococcus anophagefferens* and *Nannochloris atomus*, a cyanobacterium, *Synechocystis salina*, has been observed in summer from several sites (Appendix I, Plate 1). Another type of coccoidal cyanobacterium (tentatively *Aphanocapsa* sp.) has also been observed, mostly in summer with cells form a loose colony within mucilage, with individual cells ~1 µm in diameter (Appendix I, Plate 1). The occurrence of these two types of cyanobacteria was coincident, mostly in summer.

Bloom Patterns and Species Succession

The abundance and seasonal change in dominant species at sites BB01, BB02, BB04 (04a), BB05 (05a), BB07 (07a), BB09, BB12 and BB14 are shown in Fig. 6-13. The abundant species at BB10 are listed in Table 4. In order to better describe the phytoplankton change, based on the dominant species and their seasonal succession, these nine study sites are grouped into three, BB01, BB02, BB04 and BB05 in the northern section; BB07 and BB09 in the middle section; and BB10, BB12 and BB14 in the southern section.

The abundant species and their seasonal succession were similar among the four sites (BB01, BB02, BB04 and BB05) in northern section of Barnegat Bay (Fig. 6-9). In winter, the most abundant species was *Prorocentrum minimum*. Diatoms *S. costatum* and *Th. minima* were present at slightly lower cell density, as well as several Cryptophytes and Prasinophytes *Pryamimonas* species. The density peak of *P. minimum* was mainly in January-February. Its cell density varied among sites, but the highest was observed at BB04, reaching about $3 \times 10^6 \text{ L}^{-1}$. The winter peak of *P. minimum* was documented by Mountford (2013) with similar density level, although he noted the peak at November-

December. In spring, species succession from March to June was very dynamic. In April and early May, a bloom level (10^7 L^{-1}) of a small green flagellate was observed. The species is spherical, about 3~5 μ in diameter with two flagella about cell length (Appendix I, Plate 4). It is tentatively named as *Chlamydomonas* sp. 'c' as it fits best the description by Campell (1973). This species seems to be prevalent both temporally and spatially in northern BB, as it was encountered as early as January-February, although at lower cell density ($10^5 \sim 10^6 \text{ L}^{-1}$). The bloom of the *Chlamydomonas* species was quickly replaced by a massive bloom of a species of *Chaetoceros* (tentatively, *Ch.* cf. *tenuissimus*) in later May-June. The highest cell density reached over $2 \times 10^8 \text{ L}^{-1}$ at BB04 near the Toms River. The species is small, with apical axis about 3 to 5 (6) μm , setae fine and long (Appendix I, Plate 15). The bloom of *Ch.* cf. *tenuissimus* collapsed quickly in June, while various other species became abundant, including *C. choctawhatcheeana*, *Plagioselmis* sp., *Teleaulax acuta* and *Pyramimonas* spp.. From late June through August-September, a typical summer bloom with 'picoplankton' dominance was observed. Pico-cocoids, (1) 2-4 (5) μm in size, mainly comprised of *Nannochloris atomus*, *Synechocystis salina*, and small diatoms, *C. choctawhatcheeana* and *C. atomus* became abundant. Despite the similarity, there were a few major differences among these northern sites. The abundance of the bloom species, including *P. minimum*, *Ch.* cf. *tenuissimus*, and *C. choctawhatcheeana*, were found to be highest at BB04 compared to the other three sites. At sites BB04 and BB05, *C. choctawhatcheeana* became abundant in March-April, earlier than at BB01 and BB02. In late summer, a skinny and delicate diatom, possibly *Phaeodactylum ? tricoratum* (Appendix I, Plate 17), became abundant at BB04 and BB05, but not at BB01 and BB02.

Sites BB07 and BB09 are located in southern Barnegat Bay, close to Barnegat Bay Inlet. Phytoplankton communities at these two sites were abundant with diatoms most of the time. At BB07, several *Chaetoceros* species were abundant in May-June. In addition, the small centric diatoms *C. atomus* and *Th. minima* dominated the phytoplankton community during spring-early summer season (Fig. 10). A mix of *N. atomus*, *S. salina*, and Cryptophytes *Plagioselmis* and *Teleaulax acuta*, as well as *Gyrodinium flagellare*, developed from late June and reached highest abundance in August-early September. Diatoms *C. atomus* and several *Pseudo-nitzschia* species were observed during winter

months. As at BB05, the skinny and delicate diatom *Phaeodactylum ? tricornatum* was observed at bloom level in August-early September. At BB09, diatoms dominated the phytoplankton community in January-February and July-August. Green algae, *Chlamydomonas* spp. were mostly observed in summer (Fig. 11). The dinoflagellate *Gyrodinium estuariale* was detected frequently from April to September, with the highest abundance in September 2011 (10^6 L^{-1}). Cryptophytes, mainly *Teleaulax acuta* and *Plagioselmis* spp., were observed throughout most of the year, with higher abundance during May-July. It's worth mentioning that the year-to-year change in phytoplankton community was significant. While phytoplankton in September 2011 was dominated by pico-cocoids (10^8 L^{-1}), *Gyrodinium* sp. (10^6 L^{-1}) and *Nitzschia longissimum* (10^6 L^{-1}), phytoplankton in September 2012 was abundant with cryptophytes and diatoms, such as small centric diatoms and *Chaetoceros* spp. Some big diatoms, *Lithodesmium undulatum* and *Helicotheca tamesis* were detected at relatively low level (10^4 L^{-1}). The abundance of phytoplankton was low in 2012 compared to other sites. This is consistent with chlorophyll *a* measurements (Fig. 5).

Phytoplankton assemblages at BB10, BB12 and BB14 were dominated by diatoms during most of the year (Table 4, Figs. 12 and 13). High abundance of *A. glacialis* and *S. costatum* were observed in January-February, and again in August. The spring phytoplankton bloom was mainly comprised of the small centric diatom *Th. proschkinae* and cryptophytes, but at low abundance. These results are consistent with chlorophyll *a* data, showing relatively low values from March to June ($0.4\sim 2.5 \mu\text{g/L}$, Fig. 5). Several *Pseudo-nitzschia* species have been observed from BB12 and BB14, with the maximum total cell density reaching 10^6 L^{-1} . Similar to BB09, the phytoplankton community was dominated by pico-cocoids (10^8 L^{-1}) in August 2011, whereas in August 2012, it was abundant with chain-forming diatoms *S. costatum*, *S. menzelii*, *Cerataulina pelagica*, and *Leptocylindrus minimus* etc. Dinoflagellates, including *G. flagellare*, *Prorocentrum triestinum* and *Akashiwo sanguinea* were observed in August-September in both years, but at low abundance ($10^5 \sim 10^6 \text{ L}^{-1}$). More pronounced year-to-year variation in the phytoplankton community in southern sites is more likely due to greater tidal exchange and water circulation in south than in the north.

Overall, we observed pronounced seasonal change of dominant species and bloom patterns from north to south in the BB-LEH estuary. The phytoplankton community in northern Barnegat Bay, from winter to fall, was dominated successively by *P. minimum* and some large and chain-forming diatoms → small Chlorophycean flagellate → spine-forming *Chaetoceros* → coccoidal picoplankton and small centric diatoms. In southern Barnegat Bay and Little Egg Harbor, phytoplankton was dominated from winter to fall by a succession of the diatoms *S. costatum* and *A. glacialis* → small centric diatoms → diatoms and Cryptophytes and Chrysophytes → diatoms *Skeletonema* spp., *C. pelagica* and *Leptocylindrus minimus*. We also noticed overlap of several species from northern to southern sites. For instance, *Chlamydomonas* sp. 'c' and *Chaetoceros* cf. *tenuissimus* were abundant at sites BB01, BB02, and BB04a to BB05. *Phaeodactylum ? tricornatum* was found most abundant at sites BB04, BB05 and BB07; it was also observed but at less abundance at BB12 and BB14. *S. menzelii* was observed mostly from southern sites BB10, BB12 and BB14. The spatial differences in the species are likely due to their salinity tolerance. Generally, the promotion of blooms or dominance of certain species can be regulated by various hydrological and chemical factors, as well as biological processes. In addition to the salinity regimes, phytoplankton growth and species succession are also affected by nutrient availability and nutrient ratios. Nutrient enrichment experiments by Seitzinger et al. (2001) showed that phytoplankton growth in Barnegat Bay is limited firstly by N and secondly by P in summer, and co-limited by N+P in fall. However, she also noted that in summer there might be additional factor(s) limiting phytoplankton other than N and P. Grazing is another key factor influencing phytoplankton composition and growth via top-down control. Additionally, virus infection also may be associated with the collapse of some species, as noted in earlier studies (Sieburth et al. 1988). BB-LEH is a typical estuarine ecosystem affected by huge impacts from human activities. It is also a unique system with characteristic hydrological, biological and ecological features. Studies on nutrient-phytoplankton-zooplankton interrelationships in BB-LEH, to our knowledge, are scarce. More studies specific to the BB-LEH ecosystem are needed in order to better understand nutrient effects, phytoplankton community change and related food web alteration in the system.

Comparison with Previous Studies

One of the main characteristics of phytoplankton in BB-LEH is the seasonal dominance of picoplankton with size range of 1-3 μm . Numerically, picoplankton composed a high percentage of phytoplankton abundance during June through August-September. Those small phytoplankters were grouped as ‘ultraplankton’ in an earlier paper (Mountford 2013), and often composed of several different groups of algae (Olsen and Mahoney 2001). We observed the dominance of picoplankton, as pico-cocoids in the present study, in summer from June through September, which is consistent with previous studies. The species composition of picoplankton is also comparable to previous studies. In northern Barnegat Bay, it is mainly composed of *Nannochloris atomus*, coccoidal cyanobacteria, and some unknown green cocoids. In Little Egg Harbor, dominance of pico-cocoids was observed in August-September 2011, along with what may have been a brown tide. In 2012, brown tide was detected from some sites in current study, but did not reach bloom level (Table 5). The maximum abundance of pico-cocoids in the present study was comparable to the survey during summers of 1967 through 1970 (Mountford 2013), but somewhat (one magnitude) lower than in 1987 survey (Olsen 1989, Olsen and Mahoney 2001). A couple reasons may account for the differences. First, most sites in the 1987 and following NMFS surveys were in the locations near a shoreline prominence, pier or bridge (Olsen 1989, Olsen and Mahoney 2001). It is possible, due to winds and advection, that phytoplankton biomass may have accumulated around such locations, while all our sites are located in open water. For instance, the maximum chlorophyll *a* value from 2011-2012 (NJDEP data) was lower than that from the 1987 survey (33 $\mu\text{g l}^{-1}$, Olsen 1989), but more comparable to those from the 1967-1970 surveys (15 to 25 $\mu\text{g l}^{-1}$, Mountford 2013). Second, it needs to be mentioned that the size range for ‘picoplankton’ in Olsen and Mahoney (2001) was wider, 1-5 μm .

The major algal groups and most of the species, especially larger ones (> 20 μm), in the current study are comparable with previous studies. However, to the best of our knowledge, several species from the present study were not documented in previous studies of the BB-LEH especially in consideration of their abundance/dominance in the phytoplankton community and possible ecological significance.

Synechocystis salina. A coccoidal cyanobacterium, solitary or two cells together, with individual cells about 1.5-3 μm in size. It more often appears as two semicircular cells together, similar to *Nannochloris*, but the cells look more homogeneous. It best fits the description in Komarek and Anagnostidis (1998). The species is planktonic in salty and alkaline waters. Massive blooms of this species color the water green. The species is known from the whole of Europe and central Asia. We found this species abundant in summer, mostly in Barnegat Bay, but also from Little Egg Harbor, BB14.

***Aphanocapsa* sp.** A colonial coccoidal cyanobacterium with individual cells about ≤ 1 μm in size, spherical or oval, and forming loose colonies in light mucilage. It is often found abundant in summer, more in northern sites, but also in LEH. Its occurrence is often associated with *Synechocystis salina*.

***Chalmydomonas* sp. 'c'**. A Chlorophycean flagellate, cells spherical, about 3-5 (6) μm , with two flagella equal to cell length. The characteristic feature is separation of the cell wall from the protoplast by a hyaline space, which leads us to the name as described in Campbell (1973). However, the salinity range (20 to 25 ppt) of the species where we found it is higher than documented from Gales Creek (2 to 14 ‰). Campbell (1973) observed the species from August to December. We found it as early as January and it became dominant in April-May, more often associated with *Pseudopedinella pyriforme*. Most of the previous and on-going monitoring programs in BB-LEH have focused on the period May to November.

Chaetoceros* cf. *tenuissimus. As described earlier in this report, this species is small, with apical axis about 3 to 5 (6) μm , setae fine and long, not like real *Ch. tenuissimus* which possesses short setae (Tomas 1997). It bloomed in May-June with other *Chaetoceros* species in northern BB. *Chaetoceros* species were documented in a previous Barnegat Bay survey and found sometimes abundant (Schuster 1999). But they did not seem to be a major component of the phytoplankton community in previous studies.

Comparison with phytoplankton data from previous studies can be difficult, and even more so for BB-LEH, because 1) different methodologies were used by different laboratories in previous studies; and 2) most of the abundant or dominant species are

small, within size range of 1-15 μm . This is especially true for picoplankton, within which several size and morphologically similar species often coexist. More taxonomic work is required to better understand the composition of small phytoplankton. In addition, the Barnegat Bay ecosystem may be changing due to the rapidly developing watershed and pollution control efforts in the past decade. This is especially the case in northern Barnegat Bay. Because of its shallowness and long residence time, its phytoplankton community may be more susceptible to alteration following changes of river discharge, nutrients and any hydrological modification.

Harmful Algal Blooms and HAB Species

Harmful algal blooms (HABs) are of increasing concern in coastal waters due to their adverse effects on the health of other marine organisms and people. HABs have often been linked to local fish kills. Causes include reduction in invertebrates as well as loss of local habitats through several mechanisms, including toxin production, predation, particle irritation, induced starvation, and localized water discoloration and anoxic condition. The major HABs species, as well as their maximum abundance and occurrence at sites in this study are listed in Table 6.

Brown tide *Aureococcus anophagefferens*

Brown tide has been one of the major concerns in Barnegat Bay-Little Egg Harbor system. The brown tide alga, *Aureococcus anophagefferens*, can reduce the ingestion of nutritious algae in bay scallop larvae, keeping the organism unable to ingest enough high quality food to survive (Gallager et al. 1989). On the other hand, in adult suspension-feeding bivalves, *Aureococcus* can inhibit the activity of lateral cilia in the gill (Gainey and Shumway 1991), thereby reducing their growth (Bricelj 1999). In BB-LEH, the reduced growth in juvenile clams has been reported in association with high density of brown tide (Bricelj and MacQuarrie 2007). Studies show that 35% of the state's SAV (submerged aquatic vegetation) habitat in BB-LEH is at significant risk of negative impacts due to brown tide blooms (Gastrich et al. 2004).

The first confirmed detection of a brown tide bloom in New Jersey was in Tuckerton Bay, Little Egg Harbor in 1995. Recurrence of blooms were observed in 1997 and 1999

(Olsen and Mahoney 2001), followed by extensive blooms in Little Egg Harbor and adjacent water during 2000-2002. Blooms were mostly detected from May/June to August, sometimes in April. Studies from 2000-2002 showed that high abundance blooms had originated and persisted longest in Manahawkin Bay, which is the connecting section of the BB and LEH system. But blooms of low abundance had occurred at all locations in BB-LEH (Gastrich et al. 2004).

During this study, we have worked on the methodology of brown tide detection, using polyclonal antibody labeling and fluorescence microscopic observation with *Aureococcus* culture (NCMA, CCMP1791). We measured several samples from BB09 and BB12 and BB14 in summer (Table 5), and detected a low density of brown tide in most of the samples. The result may indicate that brown tide may be a part of the natural phytoplankton composition in BB-LEH.

Prorocentrum minimum

The species is considered potentially toxic to humans with rare cases of Venurpin shellfish poisoning. Studies have shown the ingestion of this species might alter the absorption capability in oyster larvae. Bloom density of *P. minimum* actually kills juvenile oysters and bay scallops, possibly by interfering in the shellfish's ability to produce digestive enzymes or by causing atrophy of digestive tissue (Wikfors 2005).

P. minimum has been observed in BB-LEH during 2011-2012 from over 30% of total samples. Bloom levels of this species were mostly detected in winter, particularly at BB04, with a maximum density of $2.5 \times 10^6 \text{ L}^{-1}$. *P. minimum* has been consistently abundant in BB-LEH, as noted by Olsen and Mahoney (2001). The winter peak we recorded is consistent with that from a 1967-1970 survey (Mountford 2013). Moderate abundance was also found in spring, consistent with the NJDEP HABS monitoring data (<http://www.state.nj.us/dep/bmw/phytoplankton.htm>). Another two *Prorocentrum* species, *P. triestinum* and *P. micans*, have been also observed, but at lower frequency and abundance (Table 6). All three species have been recorded previously from BB-LEH (Mountford 2013) and other New Jersey coastal waters (Gastrich 2000).

Scripsiella trochoidea

This species is usually considered non-toxic. However, a recent laboratory study showed that 10 cells ml⁻¹ of *S. trochoidea* could cause 100% and 70% mortality in shellfish and hard clam larvae, respectively (Tang and Gobler 2012). This species has been recorded from BB-LEH in previous surveys. We found this species mainly from BB09 and BB14 at low abundance (Table 6).

***Chaetoceros* spp.**

These spine-forming diatoms are considered toxic because their spines can physically clog and damage fish gills. The death of fish and crustaceans may occur when a large number of the spiny phytoplankton becomes trapped in the gills, resulting in mucus accumulation and respiratory failure, and bacteria infection (Rensel 1993). As documented in the present report, we have observed massive *Chaetoceros* blooms (10⁸ L⁻¹), composed mainly of a small type, *Ch. cf. tenuissimus*, in northern BB (Fig. 6-9). Such a high level of *Chaetoceros* has not been reported in previous studies. Its effects on other organisms in the food web are unknown. Other *Chaetoceros* species include *Ch. decipiens*, *Ch. socialis*, *Ch. lorrenzianus* and *Ch. subtilis*, most observed in relatively low abundance (10⁵ to 10⁶ L⁻¹).

***Pseudo-nitzschia* spp.**

Pseudo-nitzschia is a long, slender pennate diatom that may produce domoic acid (DA), the toxin responsible for amnesic shellfish poisoning (ASP). The toxin is known to contribute to the deaths of seabirds, sea otters and sea lions. The presence of DA can cause negative economic consequences in shellfish harvesting. Several *P-n* species have been observed in 2011-12 samples, including *P-n. pungens*, *p-n australis*, *P-n. seriata*, *P-n. delicatissima* and *P-n. fraudulenta*. They were most often detected at BB12 and BB14, and occasionally at BB07 and BB05. In most cases, the cell density was at magnitude of 10⁵ L⁻¹, and coexistence of two to three species was also observed. The highest abundance was found in April at BB14, with *P-n. pungens* of 6.8 × 10⁶ L⁻¹. *P-n. pungens*, *P-n. australis* and *P-n. seriata* from the US West Coast have been shown to produce DA (Bushaw-Newton and Sellner 1999). Toxin production of the *Pseudo-nitzschia* species, and their impacts to other organisms are unknown in BB-LEH.

Akashiwo sanguinea

This species has synonyms including *Gymnodinium sanguineum*, *G. nelsonii* and *G. splendens*, and is one of the largest dinoflagellates in the Bay. It was frequently present in samples from 2011-2012, but at low density. The highest density was found at BB04, $> 4 \times 10^4 \text{ L}^{-1}$. Low density of this species has also been recorded in previous studies (Olsen and Mahoney 2001). An association between blooms of *A. sanguinea* and fish kills has been reported, but so far a toxin has not been isolated from this species. A red tide caused by *A. sanguinea* was coincident with widespread seabird mortality in Northeastern Monterey Bay, California. It was the first documented case of a tide causing harm to birds (Jessup et al. 2009).

Biovolume Calculation and Carbon Biomass Estimation

While chlorophyll *a* is usually a routine parameter in water quality monitoring, carbon (C) is the general currency in biological models (Glibert et al. 2010). Unlike chlorophyll *a*, there is no direct in-situ measurement for phytoplankton carbon biomass. It is usually estimated from cell biovolume through the microscopic measurements. Biovolume measurements of abundant species are listed in Table 7. Carbon biomass was then estimated based on biovolumes using the equations from literature (Eppley et al. 1970): $\log C = -0,29 + 0,757 \log V$ for diatoms and $\log C = -0,6 + 0,94 \log V$ for non-diatoms. Calculated total biovolume and estimated carbon biomass of each site are plotted in Fig. 14-21.

Image Documentation

Long-term data comparison can be difficult because of taxonomic issues. In most cases, sample analyses were performed by different laboratories or personnel using different references. More difficulties may be encountered for BB-LEH phytoplankton comparisons because the majority of phytoplankton is composed of small taxa. For instance, some centric diatoms may appear as different shapes, such as rectangle or square, when observed in girdle view, and round-ish in valve view. This makes microscopic identification extremely difficult, especially under lower magnification. As part of the effort for taxonomic accuracy, images were taken during sample analysis to

provide documentation for future reference and comparisons. Image documentation on some major species is presented in Appendix I, Plate 1-20.

SUMMARY

During the year-one study, 151 monthly and biweekly samples were collected and analyzed from 9 sites. We recorded 135 taxa; 53% were diatoms and 18% were dinoflagellates. Most of the common species range in size from 2 to 20 μm (nanoplankton), and a majority fall within 2 to 10 μm . The major algal groups and most of the species in the current study are comparable with previous studies. However, several abundant/dominant species with size range of <1 to 5(6) μm were, to the best of our knowledge, not formerly recorded. Further work on the taxonomy of these species is essential, especially in consideration of their abundance/dominance in the phytoplankton community and possible ecological significance.

Seasonal changes in the phytoplankton community of BB-LEH were investigated at nine sites spreading from north to south of the embayment. Species composition, dominant species succession and bloom patterns were documented from August 2011 to September 2012. Pronounced seasonal changes in phytoplankton species composition and succession were detected at most sites. Phytoplankton assemblages in northern Barnegat Bay, from winter to fall, were dominated successively by *P. minimum* with some larger and chain-forming diatoms → small Chlorophycean flagellate → spine-forming chaetoceros → coccoidal picoplankton and small centric diatoms. In southern Barnegat Bay and Little Egg Harbor, phytoplankton was dominated mainly by diatoms, from winter to fall, *S. costatum* and *A. glacialis* → small centric diatoms → diatoms and Cryptophytes and Chrysophytes → Diatoms *Skeletonema* spp., *C. pelagica* and *Leptocylindrus minimus*. In addition, several dominant/ abundant species, including *Chlamydomonas* sp. 'c', *Chaetoceros* cf. *tenuissimus*, *Phaeodactylum* ? *tricornatum* and *Skeletonema menzeli*, showed more spatially specific north-to-south distribution patterns compared to most other abundant species. This is likely due to salinity tolerance. In addition, pronounced year-to-year differences in species composition were detected in LEH, possibly because of the greater tidal exchange and water circulation compared with northern Barnegat Bay. Phytoplankton blooms and species succession are regulated by

various hydrological, chemical, and biological factors. Salinity and physical exchanges, in combination with nutrient availability and species competition, may affect phytoplankton composition, and the occurrence and extent of blooms. Brown tide can utilize dissolved organic nitrogen and blooms have been associated with extended drought and corresponding elevated salinity and low freshwater input (Gastrich et al. 2004). Fortunately, severe intensive brown tide blooms were not observed and detected in 2012, and might not be in 2011 either. The bloom levels of *P. minimum* and *Chaetoceros* species detected in northern Barnegat Bay is worrisome due to their harmful factors. It is important to keep monitoring to detect reoccurrences of these species, and further investigate factors controlling species succession related to these blooms. Carter (2001), using GIS trend analysis, identified the northern part of Barnegat Bay as a common problem area based on four indicators (population, fecal coliform level, non-point N and P inputs). This area is characterized by low water turnover and dense population. We suggest further monitoring and research studies, such as on the relationship between nutrients and phytoplankton, as well as interactions between phytoplankton and other organisms in food web in this area.

Low abundance of brown tide *Aureococcus* was detected at BB09 and LEH. Several other HAB species were also detected at low density. *Pseudo-nitzschia*, a diatom producing DA toxin, was once detected at relatively high abundance (maximum 6.8×10^6 L⁻¹) in spring at BB12 and BB14, although not as dominant as the above-mentioned *P. minimum* and *Chaetoceros* species. *Pseudo-nitzschia* seriata was recorded in previous studies, but was un concerning due to its low abundance and/or frequency (Olsen and Mahoney 2001). It is unknown whether the detected density level was an occasional incidence, or whether these species had been present, but undetected. Less is known about toxin production of these *Pseudo-nitzschia* species, and any impacts they may cause to other organisms at detected density levels. Further monitoring of HAB species and related cause-effect studies should be carried out in order to better understand their occurrence and impacts.

Key characteristics of phytoplankton communities observed in this study are comparable to those found in previous studies. These include occurrence of major algal groups and

most of the larger species ($> 20 \mu\text{m}$), the dominance of picoplankton in summer, and picoplankton species composition. We observed several abundant/bloom species within the small size range of 1 to 5 ($6 \mu\text{m}$), especially in samples from northern Barnegat Bay. The maximum abundance of picoplankton is comparable to the 1967-1970 study (Mountford 1984), though somewhat (one magnitude) lower than in the 1987 survey (Olsen 1989, Olsen and Mahoney 2001). Different methodology, different site locations and the patchiness of phytoplankton may contribute to these differences.

FURTHER STUDIES

The project is continuing for a second year. Continuous analysis of seasonal changes in the 2012 and 2013 phytoplankton communities is ongoing. Further studies also include year-to-year comparisons with a focus on the occurrences and distribution of principle species and HAB species. Efforts will also be made to study the correlation between species succession and various regulating factors. Taxonomy and ecology of several newly documented abundant/dominant species will be further studied. Image documentation will continue along with sample analysis.

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REFERENCES

- Anderson D.M., D.M. Kulis and E.M. Coper. 1989. Immunofluorescent detection of the brown tide organism *Aureococcus anophagefferens*. In Coper E.M., V.M. Bricelj, and E.J. Carpenter (Eds). *Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms*. Springer-Verlag, Berlin, pp. 213-228.
- Anderson D.M., B.A. Keafer, D.M. Kulis, R.M. Waters and R. Nuzzi, 1993. An immunofluorescent survey of the brown tide chrysophyte *Aureococcus anophagefferens* along the northeast coast of the United States. *Journal of Plankton Research* 15:563-580.
- Bricelj V.M. and D.J. Lonsdale, 1997. *Aureococcus anophagefferens*: causes and ecological consequences of brown tides in U.S. Mid-Atlantic coastal water. *Limnology and Oceanography* 42: 1023-1038.
- Bricelj V.M., 1999. Perspectives on possible factors influencing the abundance of hard clams. In: Schlenk C.G. (Ed.): *Workshop on hard clam population dynamics research priorities for the south shore of Long Island*. Port Jefferson, New York. NY Sea Grant, Stony Brook, NY.
- Bricelj V.M. and S.P. MacQuarrie, 2007. Effects of brown tide (*Aureococcus anophagefferens*) on hard clam *Mercenaria mercenaria* larvae and implications for benthic recruitment. *Marine Ecology Progress Series* 331:147-159.
- Bushaw-Newton K.L. and K.G. Sellner, 1999 (on-line). Harmful algal blooms. In NOAA's State of the Coast Report. Silver Spring, MD. National Oceanic and Atmospheric Administration.
- Campbell P.H., 1973. Studies on brackish water phytoplankton. Sea Grant publication UNC-SG-73-07. 406pp.
- Carter G. P., 2001. Eight characterizing indicators in the Barnegat Bay watershed, Ocean County, New Jersey. *Journal of coastal research* SI 32:82-101.
- Dortch Q., R. Robichaux, S. Pool, D. Milsted, G. Mire, N.N. Rabalais, T.M. Soniat, G.A. Fryxell, R.E. Turner and M. L. Parsons, 1997. Abundance and vertical flux of *Pseudo-nitzschia* in the northern Gulf of Mexico. *Marine Ecology Progress Series* 146:249-264.
- Eppley R.W., F.M.H. Reid and J.D.H. Strickland, 1970. Estimates of phytoplankton crop size, growth rate, and primary production. *Bulletin of the Scripps Institute of Oceanography* 17:33-42.
- Gainey, L.F. and S.E. Shumway, 1991. The physiological effects of *Aureococcus anophagefferens* ("brown tide") on the lateral cilia of bivalve molluscs. *Biology Bulletin* 181:298-306.
- Gallagher Jr. L.F., D.K. Stoecker and V.M. Bricelj, 1989. Effects of the brown tide algal on growth, feeding physiology and locomotory behavior of scallop larvae (*Argopecten*

irradians). In Cospser E. M., V. M. Bricelj and E. J. Carpenter (Eds): Novel Phytoplankton Blooms: Causes and impacts of recurrent brown tides and other unusual blooms. Lecutre Notes on Coastal and Estuarine Studies. Berlin: Springer-Verlag. p. 511-541.

Gastrich M.D., 2000. Harmful algal blooms in coastal waters of New Jersey. New Jersey Department of Environmental Protection. Division of Science. Report.

Gastrich M.D., R. Lathrop, S. Haag, M.P. Weinstein, M. Danko, D.A. Caron and R. Schaffner, 2004. Assessment of brown tide blooms, caused by *Aureococcus anophagefferens*, and contributing factors in New Jersey coastal bays: 2000-2002. Harmful algae 3:305-320.

Glibert P.M., J.I. Allen, A.F. Bouwman, C.W. Brown, K.J. Flynn, A.J. Lewitus and C. Madden, 2010. Modeling of HABs and Eutrophications: status, advances and challenges. Journal of Marine Systems 83:262-275.

Gobler C.J., D.J. Lonsdale and G.L. Boyer, 2005. A review of the causes, effects, and potential management of harmful brown tide blooms caused by *Aureococcus anophagefferens* (Hargarves et Sieburth). Estuaries 28:726-749.

Gobler C. J., D.L. Berry, S.T. Dyhrman, et al., 2011. Niche of harmful alga *Aureococcus anophagefferens* revealed through ecogenomics. Proceedings of the National Academy of Sciences 108:4352-4357.

Guo Q., N.P. Psuty, G.P. Lordi, S. Glenn, M.R. Mund, and M.D. Gastrich, 2004. Hydrographic study of Barnegat Bay. New Jersey Department of Environmental Protection. Division of Science, Research and Technology. Technical report. 4pp. http://state-of-coast.noaa.gov/bulletins/html/hab_14/hab.html.

Jessup D.A, M.A. Miller, J.P. Ryan, H.M. Nevins, H.A. Kerkering, A.Mekebri, D.B. Crane, T.A. Johnson and R.M. Kudela, 2009. "Mass stranding of marine birds caused by a surfactant-producing red tide". *PLoS ONE* 4 (2): e4550. doi:10.1371/journal.pone.0004550

Kennish M.J., S.B. Bricker, W.C. Dennison, P.M. Glibert, R.J. Livingston, K.A. Moore, R.T. Noble, H.W. Paerl, J.M. Ramstack, S. Seitzinger, D.A. Tomasko and I. Valiela, 2007. Barnegat Bay-Little Egg Harbor estuary: Case study of a highly eutrophic coastal bay system. Ecological Applications 17 (5) supplement, pp: S3-S16.

Kennish M.J. 2001. Physical description of the Barnegat Bay-Little Egg Harbor estuarine system. Journal of Coastal Research, SI, 32 13-27.

Kennish M.J., B. M. Fertig, and R.G. Lathrop, 2013. Assessment of nutrient loading and eutrophication in Barnegat Bay-Little Egg Harbor, New Jersey in support of nutrient management planning. <http://marine.rutgers.edu/main/Front-Page-News/Assessment-of-Nutrient-Loading-and-Eutrophication-in-Barnegat-Bay-Little-Egg-Harbor-New-Jersey-in-S.html>

- Komarek J. and K. Anagnostidis., 1998. Süßwasserflora von Mitteleuropa. 19/1. Cyanoprokaryota. Teil 1:Chroococcales. Spektrum Akademischer Verlag. Heidelberg. 548pp.
- Livingston R. J., 2007. Phytoplankton bloom effects on a gulf estuary: water quality changes and biological responses. *Ecological Applications*. 17(5) Supplement: S110-128.
- Mahoney J.B., P.S. Olsen and D. Jeffress., 2006. Bloom history of picoplankter *Aureococcus anophagefferens* in the New Jersey Barnegat Bay-Little Egg Harbor system and Great Bay, 1995-1999.
- Martin G.W., 1929. Dinoflagellates from marine and brackish waters in New Jersey. University of Iowa Studies in Natural History, XII, Ames, Iowa. 32pp.
- Mountford K., 1967. The occurrence of Pyrrophyta in a brackish cove-Barnegat Bay, New Jersey at Mantoloking, May through December, 1966. *Bulletin of the New Jersey Academy of Science*, 12: 9-12.
- Mountford K., 1971. Plankton studies in Barnegat Bay. Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey. 147pp.
- Mountford, K., 2013. Phytoplankton. In M.J. Kennish and R.A. Lutz (Eds): *Ecology of Barnegat Bay, New Jersey*. Springer-Verlag, New York Inc. doi: 10.1029/LN006p0052
- Olenina I., S. Hajdu, L. Edler, A. Andersson, N. Wasmund, S. Busch, J. Goebel, S. Gromisz, S. Huseby, M. Httunen, A. Jaanus, P. Kokkonen, I. Ledaine and E. Niemkiewicz, 2006. Biovolumes and size-classes of phytoplankton in the Baltic Sea. *HELCOM Balt. Sea Environ. Proc. No. 106*, 144pp.
- Olsen P.S. and J.B. Mahoney, 2001. Phytoplankton in the Barnegat Bay-Little Egg harbor estuarine system: species composition and picoplankton bloom development. *Journal of Coastal Research SI 32*:115-143.
- Olsen P.S., 1989. Development and distribution of a brown-water algal bloom in Barnegat Bay, New Jersey with perspective on resources and other red tides in the region. In Coper E.M., V.M. Bricelj, E.J. Carpenter (Eds): *Novel Phytoplankton Blooms: Causes and impacts of recurrent brown tides and other unusual blooms*. *Lecture Notes on Coastal and Estuarine Studies*. Berlin: Springer-Verlag. p. 189-212.
- Pecchioli J.A., R. Lathrop and S. Haag, 2006. Brown tide assessment project in NJ coastal waters: A comparison of three bloom years (2000-2002) with two non-bloom years (2003-2004). Research project summary. Division of Science, Research and Technology, NJDEP.

Ren L., N. N Rabalais, R.E. Turner, W. Morrison and W. Mendenhall, 2009. Nutrient limitation on phytoplankton growth in Upper Barataria Basin, Louisiana: Microcosm bioassays. *Estuaries and Coasts* 32:958-974.

Rensel J.E., 1993. Severe blood hypoxia of Atlantic Salmon (*Salmo salar*) exposed to the marine diatom *Chaetoceros concavicornis*. In T.J. Smayda and Y. Shumizu (eds): Toxic phytoplankton blooms in the sea. Elsevier Science Publishers, B. V. Amsterdam. p. 625-630.

Schuster R., 1999. Annual summary of phytoplankton blooms and related conditions in New Jersey Coastal waters, summer of 1999. NJDEP Water Monitoring Report.

Seitzinger S.P. and Piling I.E., 1993. Eutrophication and nutrient loading in Barnegat Bay: Initial studies of the importance of sediment-water nutrient interactions. Report No. 92-24F, the Academy of Natural Sciences, Philadelphia, Pennsylvania.

Seitzinger S.P and R.M. Styles, 1999. A synthesis of water quality and primary production in the Barnegat Bay ecosystem; Technical Report. Prepared for the Barnegat Bay National Estuary Program, Rutgers University, New Brunswick, New Jersey.

Seitzinger S.P., R.M. Styles and I.E. Pilling, 2001. Benthic microalgal and phytoplankton production in Barnegat Bay, New Jersey (USA): Microcosm experiments and data Synthesis. *Journal of Coastal Research* SI 32: 144-162.

Sieburth J. McN, P.W. Johnson and P.E. Hargraves, 1988. Characterization of *Aureococcus anophagefferens* gen.et.sp. nov. (Chrysophyceae): the dominant picoplankter during the summer, 1985 bloom in Narragansett Bay, Rhode Island. *Journal of Phycology* 24:416-425.

Tang Y. and C. Gobler, 2012. Lethal effects of Northwest Atlantic Ocean isolates of the dinoflagellate, *Scrippsiella trochoidea*, on Eastern Oyster (*Crassostrea virginica*) and Northern Quahog (*Mercenaria mercenaria*) larvae. *Marine Biology* 159:199-210

Tomas C.R., 1997. Identifying marine phytoplankton. Academic Press. Harcourt Brace & Company. San Diego. 858pp.

Wienben C.M., and R.J. Baker, 2009. Contributions of nitrogen to the Barnegat Bay-Little Egg Harbor estuary: updated loading estimates. US. Geological Survey. West Trenton, New Jersey USA. Technical Report. 25pp.

Wikfors G.H. 2005. A review and analysis of a trophic interactions between *Prorocentrum minimum* and clam, oysters and scallops. *Harmful algae*. 4:585-592.

TABLES

Table 1: List of sites for phytoplankton collection in Barnegat Bay-Little Egg Harbor (August 2011-September 2012)

Site_Code	Site Description	Latitude	Longitude	Remarks
BB01	Barnegat Bay at Mantoloking	40.0400000	-74.052222	
BB02	Barnegat Bay between Silver Bay and Goose Creek	39.9776200	-74.098470	
BB04	Barnegat Bay near the Mouth of Toms River	39.9376200	-74.110140	BB04a after May 2012
BB05	Barnegat Bay above Cedar Creek	39.8845600	-74.112910	BB05a after May 2012
BB07	Barnegat Bay below Oyster Creek and above Barnegat Inlet	39.7926200	-74.153190	BB07a after May 2012
BB09	Barnegat Bay below Barnegat Inlet and close to Long Beach	39.7426200	-74.147920	
BB10	Barnegat Bay by Route 72 Bridge	39.6609500	-74.206530	
BB12	Barnegat Bay in Little Egg Harbor	39.5815100	-74.268750	
BB14	Little Egg Harbor Inlet near Beach Haven Heights	39.5112300	-74.297370	

Site_Code	Site Descripton	Latitude	Longitude	
BB04a	west of BB04, more into Tom River	39.93289	-74.14069	
BB05a	North of BB05, more near the mouth of Toms River	39.9157764	-74.1094237	
BB07a	Slightly north of BB07, closer to Oyster Creek, and still above Barnegat Inlet	39.8012861	-74.1571172	

Table 2: Summary of nutrients in surface water in BB-LEH during phytoplankton collections from August 2011 to September 2012. Summarized from NJDEP water quality data from <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>. (**TN**: total nitrogen; **TP**: total phosphorus; **TSi**: total Si; **%DN/TN**: percent of dissolved N to TN; **%DP/TP**: percent of dissolved P to TP; **%Si/TSi**: percent of to TSi; and **%DON/DIN**: percent of dissolved organic nitrogen (DON) to dissolved inorganic nitrogen (DIN)).

Site ID	TN (mg L⁻¹)	% DN/TN	% DON/DN	TP (mg L⁻¹)	% DP/TP	TSi (mg L⁻¹)	% Si/TSi
BB01	0.24~0.87	40~96	75~100	<0.01~0.07	<11~26	0.3~3.4	58~93
BB02	0.28~0.95	40~85	80~99	<0.01~0.06	<7~49	0.06~3.6	42~95
BB04a	0.52~0.87	41~95	40~99	0.01~0.06	<8~40	0.9~4.2	60~94
BB05a	0.36~0.76	<37~79	75~93	0.018~0.06	<5~40	0.15~3.6	50~99
BB07a	0.22~0.56	43~100	75~96	0.015~0.07	27~79	0.2~4.2	30~90
BB09	0.17~0.61	60~99	75~96	<0.01~0.1	<12~72	0.5~7.7	<25~97
BB10	0.18~0.78	43~>100	52~94	<0.01~0.11	<21~77	0.7~7.2	<11~90
BB12	0.17~0.95	56~>100	40~94	0.015~0.092	<31~98	2.0~5.1	<10~85
BB14	0.14~0.57	33~>100	40~97	<0.02~0.1	<5~98	1.0~3.5	<9~72

Table 3: List of phytoplankton species in Barnegat Bay-Little Egg Harbor estuary from August 2011 to September 2012. (note: A: species abundant in at least one sample; C: commonly seen but at low density; *: new records).

Taxon names	Notes
Cyanophyceae	
<i>Aphanocapsa</i> Naegeli (sp.)	A *
<i>Merismopedia</i> Meyen (sp.)	
<i>Synechocystis salina</i> Wislouch	A *
Chrysophyceae	
<i>Calycomonas ovalis</i> Wulff (syn. <i>Paulinella ovalis</i> (Wulff) Johnson, Hargraves & Sieburth)	A
<i>Calycomonas gracilis</i> Lohmann	
<i>Dinobryon</i> Ehrenber (sp.)	
<i>Dinobryon belgica</i> Meunier	
<i>Dinobryon faculiferum</i> (Willen) Willen	
<i>Ebria</i> Borgert (sp.)	
<i>Pseudopedinella pyriformis</i> Carter	A
Chlorophyceae	
<i>Chlamydomonas</i> Ehrenberg (sp.)	
<i>Chlamydomonas coccoides</i> Butcher	
<i>Chlamydomonas</i> sp. 'c' Campbell	A *
<i>Chlamydomonas</i> spp.	
<i>Nannochloris atomus</i> Butcher	A
<i>Chlorella</i> sp.	
Dictyochophyceae	
<i>Dictyocha</i> (Ehrenberg) sp	
<i>Dictyocha fibula</i> Ehrenberg	A
Pelagophyceae	
<i>Aureococcus anophagefferens</i> Hargraves	
Bacillariophyceae	
<i>Achnanthes</i> spp.	
<i>Amphora</i> spp.	
<i>Asterionellopsis glacialis</i> (Castracane) Round	A
<i>Biddulphia</i> sp.	
<i>Brockmanniella brockmannii</i> (Hustedt) Hasle, von Stosch et Syvertse	
<i>Cerataulina pelagica</i> (Cleve) Hendey	A
<i>Chaetoceros</i> sp.	
<i>Chaetoceros affinis</i> Lauder	
<i>Chaetoceros dydimus</i> Ehrenberg	
<i>Chaetoceros simplex</i> Ostenfeld	A
<i>Chaetoceros socialis</i> Lauder	
<i>Chaetoceros</i> cf. <i>tenuissimus</i> Meunier	A *
<i>Chaetoceros decipiens</i> Cleve	A

Table 3 (cont.): List of phytoplankton species in Barnegat Bay-Little Egg Harbor estuary from August 2011 to September 2012. (note: A: species abundant in at least one sample; C: commonly seen but at low density; *: new records).

Taxon names	Notes
<i>Chaetoceros lorenzianus</i> Grunow	
<i>Chaetoceros minimus</i> (Levander) Marino, Giuffre, Montresor & Zingone	A *
<i>Chaetoceros subtilis</i> Cleve	A *
<i>Chaetoceros subtilis</i> fo. <i>simplex</i>	C *
<i>Chaetoceros tenuissimus</i> Meunier	
<i>Cocconeis</i> spp.	C
<i>Coscinodiscus concinnus</i> Smith	C
<i>Coscinodiscus granii</i> Gough	C
<i>Cyclotella atomus</i> Hustedt	A
<i>Cyclotella choctawhatcheeana</i> Prasad	A *
<i>Cylindrotheca closterium</i> (Ehrenberg) Reimann et Lewin	C
<i>Dactyliosolen fragilissimus</i> (Bergon) Hasle	C *
<i>Entomoneis alata</i> Ehrenberg	C
<i>Entomoneis</i> sp.	
<i>Eucampia</i> sp.	
<i>Eucampia zodiacus</i> Ehrenberg	A
<i>Eunotogramma dubium</i> Hustedt	C
<i>Fallacia</i> spp.	
<i>Guinardia flaccida</i> (Castracane) Peragallo	A
<i>Guinardia striata</i> (Stolterfoth) Hasle	A
<i>Gyrosigma</i> spp.	C
<i>Haslea spicula</i> (Hickie) Lange-Bertalot	C
<i>Helicotheca tamesis</i> (Shrubsole) Ricard	*
<i>Leptocylindrus danicus</i> Cleve	C
<i>Leptocylindrus minimus</i> Gran	A
<i>Lithodesmium undulatum</i> Ehrenberg	A
<i>Meuniera membranacea</i> (Cleve) Silva et Tomas	A
<i>Minutocellus polymorphus</i> (Hargraves et Guillard) Hasle, von Stosch et Syvertsen	A
<i>Navicula</i> spp.	C
<i>Nitzschia longissima</i> (Brebisson) Ralfs	A
<i>Nitzschia</i> spp.	C
<i>Odontella aurita</i> (Lyngbye) Agardh	
<i>Odontella regia</i> (Schultze) Simonsen	
<i>Odontella rhombus</i> (Ehrenberg) Kuetzing	
<i>Phaeodactylum ? tricornutum</i> Bohlin	A
<i>Pinnularia</i> spp.	
<i>Pleurosigma salinarum</i> (Grunow) Grunow	C
<i>Pleurosigma</i> sp.	
<i>Psuedo-nitzschia australis</i> Frenguelli	C
<i>Psuedo-nitzschia delicatissima</i> (Cleve) Heiden	
<i>Psuedo-nitzschia fraudulenta</i> (Cleve) Hasle	C
<i>Psuedo-nitzschia seriata</i> (Cleve) Peragallo	
<i>Psuedo-nitzschia pungens</i> (Grunow ex Cleve) Hasle	A
<i>Psuedo-nitzschia</i> sp.	
<i>Pragiogrammopsis</i> sp.	
<i>Proboscia alata</i> (Brightwell) Sundstroem	

Table 3 (cont.): List of phytoplankton species in Barnegat Bay-Little Egg Harbor estuary from August 2011 to September 2012. (note: A: species abundant in at least one sample; C: commonly seen but at low density; *: new records).

Taxon names	Notes
<i>Rhaphoneis amphiceros</i> (Ehrenberg) Ehrenberg	C
<i>Rhaphoneis</i> Ehrenberg (sp.)	
<i>Rhizosolenia imbricata</i> Brightwell	A
<i>Rhizosolenia setigera</i> Brightwell	
<i>Rhizosolenia styliformis</i> Brightwell	A
<i>Skeletonema costatum</i> (Greville) Cleve	A
<i>Skeletonema menzelli</i> Guillard, Carpenter et Reimann	A *
<i>Thalassionema frauenfeldii</i> (Grunow) Hallegraeff	
<i>Thalassionema nitzschioides</i> (Grunow) Mereschkowsky	A
<i>Thalassiosira minima</i> Gaarder	
<i>Thalassiosira nordenskioldii</i> Cleve	A
<i>Thalassiosira proschkiniae</i> Makarova	A *
<i>Thalassiosira</i> spp.	
Dinophyceae	
<i>Akashiwo Sanguinea</i> (Hirasaka) G. Hansen	C
(Syns: <i>Gymnodinium sanguineum</i> , <i>G. nelsonii</i> , <i>G. splendens</i>)	
<i>Ceratium</i> Schrank (sp.)	
<i>Ceratium fusus</i> (Ehrenberg) Dujardin	
<i>Ceratium lineatum</i> (Ehrenberg) Cleve	C *
<i>Ceratium tripos</i> (Mueller) Nitzsch	
<i>Cochlodinium</i> Schutt (sp.)	
<i>Dinophysis acuminata</i> Claparede et Lachmann	
<i>Gymnodinium</i> Stein (spp.)	
<i>Gyrodinium cf. aureolum</i> Hulburt	C
<i>Gyrodinium estuariale</i> Hullburt	C
<i>Gyrodinium flagellare</i> Schiller	C
<i>Gyrodinium fusiforme</i> Kofoid et Swezy	
<i>Gyrodinium spiral</i> (Bergh) Kofoid & Swezy	
<i>Gyrodinium dominans</i> Hulburt	
<i>Heterocapsa triquetra</i> (Ehrenberg) Stein	
<i>Katodinium rotundatum</i> (Lohmann) Loeblich III	
<i>Prorocentrum</i> Ehrenberg (sp.)	
<i>Prorocentrum micans</i> Ehrenberg	
<i>Prorocentrum minimum</i> (Pavillard) Schiller	A
<i>Prorocentrum scutellum</i> Schroder	C
<i>Prorocentrum triestinum</i> Schiller	
(syn. <i>P. redfieldi</i> Bursa)	
<i>Protoperidinium</i> Bergh (spp.)	
<i>Protoperidinium bipes</i> (Paulsen) Balech	
<i>Scrippsiella trochoidea</i> (Stein) Loeblich III	
Raphidophyceae	
<i>Heterosigma akashiwo</i> (Hada) Hada ex Hara et Chihara	

Table 3 (cont.): List of phytoplankton species in Barnegat Bay-Little Egg Harbor estuary from August 2011 to September 2012. (note: A: species abundant in at least one sample; C: commonly seen but at low density; *: new records).

Taxon names	Notes	
Prasinophyceae		
<i>Pyramimonas</i> sp.		
<i>Pyramimonas grossii</i> Parke	C	
<i>Pyramimonas orientalis</i> McFadden, Hill et Wetherbee	A	
<i>Tetraselmis</i> spp.		
<i>Pseudoscourfieldia marina</i> (Thronsen) Manton	A	
<i>Resultor mikron</i> (Thronsen) Moestrup (possibly the same as <i>Pedinomonas minor</i> Korshikov)		
<i>Micromonas pusilla</i> (Butcher) Manton & Parker		
<i>Pachysphaera marshalliae</i> Parke		
Prymnesiophyceae		
<i>Chrysochromulina</i> sp.		
Cryptophyceae		
<i>Hemiselmis</i> Parke (sp.)		
<i>Hemiselmis virescens</i> Droop	A	
<i>Teleaulax acuta</i> (Butcher) Hill	A	*
<i>Rhodomonas salina</i> (Wislouch) Hill	A	
<i>Rhodomonas</i> sp.		
<i>Leucocryptos marina</i> (Braarud) Butcher	C	*
<i>Plagioselmis</i> (Butcher) Hill (sp.)	A	
<i>Cryptomonas</i> (Ehrenberg) sp.		
Euglenophyceae		
<i>Euglena</i> Ehrenberg (sp.)		
<i>Eutreptiella</i> de Cunha (sp.)	C	
Autotrophic ciliate		
<i>Mesodinium rubrum</i> Leegaard	C	

Table 4: Abundant species of phytoplankton at site BB10, August 2011- September 2012.

8/25/2011	1/10/2012	3/6/2012	9/17/2012
<p><i>Thalassiosira proschkiniae</i> 4.1×10^6 <i>Cylindrotheca closterium</i> 1.8×10^5 <i>Gyrosigma</i> sp. 5.8×10^4 Pico-cocoids 9.8×10^7 <i>Calycomonas ovalis</i> 6.5×10^5</p>	<p><i>Cyclotella</i> spp. 5.8×10^5 <i>Leptocylindrus minimus</i> 1.5×10^5 <i>Skeletonema costatum</i> 5.0×10^5 <i>Teleaulax acuta</i> 3.6×10^5 <i>Dinobryon faculiferum</i> 1.8×10^5 <i>Hemiselmis virescens</i> 9.1×10^4</p>	<p><i>Skeletonema menzelii</i> 7.9×10^5 <i>Guinardia striata</i> 1.9×10^5 <i>Rhizolenia imbricata</i> 8.4×10^4 <i>Dinobryon faculiferum</i> 1.8×10^5 <i>Pseudoscurfieldia marina</i> 2.3×10^5</p>	<p><i>Skeletonema menzelii</i> 6.8×10^5 <i>Cyclotella</i> sp. 7.0×10^5 <i>Teleaulax acuta</i> 3.4×10^6 <i>Gyrodinium flagellare</i> 2.3×10^5 <i>Calycomonas ovalis</i> 3.0×10^5 <i>Hemiselmis virescens</i> 4.9×10^5 <i>Pyramimonas micron</i> 2.1×10^5</p>

Table 5: *Aureococcus anophagefferens* (AA) detected from southern sites BB09, BB10 and BB14, using polyclonal antibody method.

Site	Collection date	AA (cells L ⁻¹)	<i>Synechocystis salina</i> (cells L ⁻¹)
BB07a	7/16/2012		5.3×10^8
BB09	7/2/2012	7.2×10^6	
BB09	7/2/2012	9.0×10^6	
BB09	7/16/2012	9.4×10^6	
BB09	8/6/2012	4.7×10^5	
BB12	7/16/2012	4.8×10^6	
BB12	8/6/2012	3.7×10^6	
BB14	7/16/2012	2.6×10^6	1.9×10^7

Table 6: Summary of HAB species observed in BB-LEH from August 2011 to September 2012.

Species	# of samples	Sites	Season	Abundance	Notes
<i>Prorocentrum minimum</i>	50	BB01, 02, 04	Jan-Feb	Up to 2.5×10^6	Fishkills
<i>P. triestinum</i>	8	BB14, BB07	Aug-Sept	Up to 3.4×10^5	Toxicity unknown
<i>P. micans</i>	5	BB14	June, Aug.	Up to 2.4×10^4	Toxicity unknown
<i>Chaetoceros tenuissimus</i>	32	BB01, 02, 04, 05	May-Jun, Jul-Sept	$10^6 \sim >1 \times 10^8$	Physical damage
<i>Other Chaetoceros spp.</i>	45	All sites	May-Jun, Jul-Sept	$10^6 \sim >1 \times 10^7$	Physical damage
<i>Pseudo-nitzschia spp</i>	22	BB12, 14, 07	Jan-April	$10^5 \sim >6 \times 10^6$	Domoic acid , ASP. Several species detected. See text for more info
<i>Akashiwo sanguinea</i>	14	BB04, 05, 07	Jul-Aug-Sept	$10^2 \sim >4 \times 10^4$	Fishkill and seabird mortality
<i>Scripsiella trochoidea</i>	5	BB09, 14	Jun-Jul	$4 \times 10^3 \sim >7 \times 10^4$	Shellfish larvae mortality
<i>Gyrodinium cf. aureolum</i>	35	BB02, 05, 12, 14	May-Sept	$10^4 \sim >5 \times 10^5$	Bather discomfort, moderate illness

Table 7: Biovolume measurements of dominant/abundant phytoplankton in Barnegat Bay-Little Egg Harbor, from August 2011 to September 2012.

Taxa	T r o p h y *	Shapes	Length (μm)	Width (μm)	Height (μm)	Diameter (μm)	Number of measure- ments	Biovolume (μm^3)	
								Range	Mean
Cyanophyceae									
<i>Aphanocapsa</i> sp.	A	Sphere				0.4~1	25	0.09~0.52	0.29
<i>Synechocystis salina</i>	A	Sphere				2~5	25	4.2~65	27.5
<i>Merismopedia</i> sp.	A	Sphere				1~3	10	0.5~14	11
Chrysophyceae									
<i>Calycomonoas ovalis</i>	A	Rotational ellipsoid	5~6			2.8~4	20	19-35	28
<i>C. gracilis</i>		Rotational ellipsoid	3~5			2.5~4.2	5	14~32	22
<i>Dinobryon faculiferum</i>	M	Rotational ellipsoid	7~8			3~5	3	33~92	56
<i>Dinobryon belgica</i>	M	Rotational ellipsoid	9.2~10			2.4~4.5	5	25~96	46
Chlorophyceae									
<i>Chlamydomonas</i> sp. 'c'	A	Sphere				3~6	20	14~113	59
<i>Chlamydomonas coccoides</i>	A	Sphere				5-7	7	65~179	126
<i>Chlamydomonas</i> spp.	A	Sphere				7~14		179~1436	865
<i>Nannochloris atomus</i>	A	Sphere				2~4	20	4~33	38
Dictyochophyceae									
<i>Dictyocha fibula</i>	A	Half Sphere				18~22	5	3052~5572	4186
<i>Pseudopedinella pyriforme</i>	A	Sphere				5~7	15	65~179	113

Table 7: Biovolumes of phytoplankton in Barnegat Bay-Little Egg Harbor (continued)

Taxa	T r o p h y	Shapes	Length (μm)	Width (μm)	Height (μm)	Diameter (μm)	Number of meas- ure- ments	Biovolume (μm^3)	
								Range	Mean
Pelagophyceae									
<i>Aureococcus anophagefferens</i>	A	Sphere				2~3	20	4~14	8.4
Bacillariophyceae									
<i>Asterionellopsis glacialis</i>	A	Cone + half Sphere			20~30	5~9	15	147~744	187
<i>Cerataulina pelagica</i>	A	Cylinder			28~58	8~15	15	1,406~6,154	5,173
<i>Chaetoceros cf. tenuissimus</i>	A	Cylinder			3~5	3~6	10	21~169	79
<i>Ch. tenuissimus</i>	A	Cylinder			3~6	3~5	5	27~169	78
<i>Ch. subtilis</i>	A	Cylinder			3~4	4~14	5	28~98	85
<i>Ch. affinis</i>	A	Cylinder			16-25	8~15	4	1,000~2,900	1921
<i>Ch. subtilis fo. simplex</i>	A	Cylinder			6	6	1	169	169
<i>Ch. dydimus</i>	A	Cylinder			14~21	10~15	5	924~7,324	3,246
<i>Ch. decipiens</i>	A	Cylinder			5~7	8~12	5	196~379	282
<i>Ch. minimus</i>	A	Cylinder			16~20	4	3	803~1,256	1,017
<i>Chaecoceros socialis</i>	A	Cylinder			7~10	3~5	5	54~251	176
<i>Chaetoceros spp</i>	A	Cylinder			6~25	5~15	20	282~7,459	1,533
<i>Chaetoceros sp.</i>	A	Cylinder			22~25	19~20	4	6,234~7,850	6,517
<i>Leptocylindrus minimus</i>	A	Cylinder			20~25	3	5	141~176	162
<i>Leptocylindrus danicus</i>	A	Cylinder			25~30	5~6	5	392~588	490
<i>Coscinodiscus concinnus</i>	A	Cylinder			40	60~250	5	113,040~1,962,500	803,840
<i>Coscinodiscus granii</i>	A	Cylinder			70	80~160	5	351,680~1,406,720	791.280

Table 7: Biovolumes of phytoplankton in Barnegat Bay-Little Egg Harbor (continued)

Taxa	T r o p h y	Shapes	Length (μm)	Width (μm)	Height (μm)	Diameter (μm)	Number of measure- ments	Biovolume (μm^3)	
								Range	Mean
<i>Cyclotella stomus</i>	A	Cylinder			2~4	3.5~6	10	19~113	40
<i>C. choctawhatcheeana</i>	A	Cylinder			3~5	3.5~10	15	29~392	153
<i>Cylindrotheca closterium</i>	A	Rotational ellipsoid			25~75	3~6	5	117~659	317
<i>Dactyliosolen fragilissimus</i>	A	Cylinder			25~40	7~11	5	641~3,102	1,356
<i>Eucampia zodiac</i>	A	Cylinder			12~18	20~24	5	2,512~5,425	4,052
<i>Guinardia flaccida</i>	A	Cylinder			75~90	30~40	5	32,970~75,360	51,286
<i>Guinardia striata</i>	A	Cylinder			50~64	30~50	5	35,325~125,600	72,848
<i>Gyrosigma</i> spp.	A	Prism on parallelogram	70~210	15~35	15~20			8,242~76,930	23,550
<i>Helicotheca tamesis</i>	A	Rectangular box	50~70	80~120	10		5	40,000~84,000	60,000
<i>Lithodesmium undulatum</i>	A	Prism on triangle	35~45	35~45	50~70		10	30,625~70,875	48,000
<i>Nitzschia longissima</i>	A	Rotational ellipsoid			75~120	5~10	5	267~796	560
<i>Odontella aurita</i>	A	Cylinder			35~45	30~35	5	24,727~43,273	34,194
<i>Pleurosigma</i> spp.	A	Prism on parallelogram	90~210	20~35	15			14,130~57,697	35,325
<i>Pseudo-nitzschia</i> spp.	A	Prism on parallelogram	55~80	2~6	5		10	431~1,256	628
<i>Proboscia alata</i>	A	Cylinder			300~450	5~8	5	5,887~22,608	11,304
<i>Rhizosolenia implicata</i>	A	cylinder			120~300	6.5~10	10	3,980~23,550	11,052
<i>Rhizosolenia setigera</i>	A	Cylinder			220~400	17.5~20	5	52,889~125,600	81,388
<i>Rhizosolenia styliformis</i>	A	Cylinder			300~800	20~28	5	94,200~492,352	226,080

Table 7: Biovolumes of phytoplankton in Barnegat Bay-Little Egg Harbor (continued)

Taxa	T r o p h y	Shapes	Length (μm)	Width (μm)	Height (μm)	Diameter (μm)	Number of meas- ure- ments	Biovolume (μm^3)	
								Range	Mean
<i>Skeletonema costatum</i>	A	Cylinder			6~25	5	15	117~490	243
<i>Skeletonema menzeli</i>	A	Cylinder			3~4	4~6	10	28~75	48
<i>Thalassionema nitzschioides</i>	A	parallelepiped	30~60	2~5	2~5		5	187~1,500	800
<i>Thalassionema frauenfeldii</i>	A	parallelepiped	50~100	3~5	3~5		5	450~2,500	1280
<i>Thalassiosira minima</i>	A	Cylinder			4~6	5~12	10	63~452	201
<i>Thalassiosira proschkinae</i>	A				2	2.5~6	10	10~56	39
<i>Thalassiosira nordenskiöldii</i>	A	Cylinder			10	12~37	5	1,130~10,173	3140
<i>Thalassiosira</i> spp.	A	Cylinder			5	10~30	7	392~3,532	1271
<i>Navicula</i> spp. <50 μm	A	Prism on parallelogram	20~40	5~10	5		10	250~1,000	600
<i>Navicula</i> spp. <100 μm	A	Prism on parallelogram	55~80	8~12	5		5	1,100~2,400	1,750
<i>Licmophora</i> sp.	A	Prism on parallelogram	60~65	20	45		5	13,500~14,600	14,165
<i>Haslea</i> sp.	A	Prism on parallelogram	120~150	25~28	5		3	8,400~9,375	8125
Diatom centrics <5 μ	A	Cylinder			3~4	4~5	10	38~78	60
Diatom centric 5~10 μ	A	Cylinder			5~7	6~10	10	141~549	301
Diatom centric 10~20 μ	A	Cylinder			6~10	12~18	10	678~2,543	1,607
Diatom centric >30 μ	A	Cylinder			10~15	32~36	4	8,038~15,260	10,889
Diatom pennates	A	Prism on parallelogram	15~50	5~8	4~5		10	150~1,000	450

Table 7: Biovolumes of phytoplankton in Barnegat Bay-Little Egg Harbor (continued)

Taxa	T r o p h y	Shapes	Length (μm)	Width (μm)	Height (μm)	Diameter (μm)	Number of measure- ments	Biovolume (μm^3)	
								Range	Mean
<i>Akashiwo sanguinea</i>	H	Ellipsoid	70~80		30	45~50	5	49,455~62,800	51,653
<i>Ceratium lineatum</i>	A		120~140			35~45	5	48,000~60,000	51,000
<i>Prorocentrum minimum</i>	A	Ellipsoid		12	15~21	15~18	5	937~1,805	1401
<i>Prorocentrum micans</i>	A	Ellipsoid	50	25		30~40	5	12,567~43,790	27,632
<i>Prorocentrum triestinum</i>	A	Ellipsoid	18~22	6~8		9~12	5	580~1,105	732
<i>Gyrodinium flagellare</i>	A	Ellipsoid	8~12	4~6		5~7	4	84~264	157
<i>Gyrodinium estuariale</i>	A	Ellipsoid	12~15	7~9		8~10	5	351~706	544
<i>Gyrodinium fusiforme</i>	H	Ellipsoid	70~75	15		28~35	5	15,386~20,606	18,337
<i>Heterocapsa triquetra</i>	A	Ellipsoid	18~20	12		14~16		1,582~2,009	1,789
<i>Gyrodinium cf. aureolum</i>	A	Ellipsoid	18~25	12~15		10~12	5	1,130~2,355	1,646
<i>Heterosigma akashiwo</i>	A	Ellipsoid	10~15	8~10		8~10	5	334~785	508
Prasinophyceae									
<i>Pyraminomonas grossii</i>	A	Sphere				5~8	10	65~267	180
<i>Pyraminomonas orientalis</i>	A	Sphere				4~6	15	33~113	65
<i>Pseudoscourfieldia marina</i>	A		3~5	2		2~3	10	6~16	12
<i>Resultor mikron</i>	A	Ellipsoid	1.5~2.5	1		1	5	0.8~1.3	1.0
<i>Micromonas pusilla</i>	A	Rotational ellipsoid	2~3			1.5	5	2.4~3.5	2.9
<i>Pachysphaera marchalliae</i>	A	Sphere				7, 8	2	179, 268	221

Table 7: Biovolumes of phytoplankton in Barnegat Bay-Little Egg Harbor (continued)

Taxa	Trophy	Shapes	Length (µm)	Width (µm)	Height (µm)	Diameter (µm)	Number of measurements	Biovolume (µm ³)	
								Range	Mean
Cryptophyceae									
<i>Hemiselmis virescens</i>	A	Rotational ellipsoid			4~5	2~3	5	8~23	15
<i>Plagioselmis</i> spp.	A	Cone + half sphere			5~10	3~5	10	12~65	33
<i>Teleaulax acuta</i>	A	Cone + half sphere			12~15	5~7	10	78~192	131
<i>Rhodomonas salina</i>	A	Rotational ellipsoid			10~12	7.5~8.5	5	147~227	184
<i>Rhinomonas</i> sp.	A	Rotational ellipsoid			6~8	3~5	4	28~105	59
<i>Leucocryptos marina</i>	A	Cone + half sphere			9~12	4~6	5	38~113	69
Euglenophyceae									
<i>Eutreptiella</i> sp.	A	Rotational ellipsoid			18~25	5~6	5	235~641	414
<i>Euglena</i> sp.	A	Rotational ellipsoid			20~32	5~7	4	262~821	546
Others									
<i>Mesodinium rubrum</i>	A	Rotational ellipsoid			30~40	25~30	5	9,812~18,840	14,360

*Trophy abbreviations:

A: autotrophic

H: heterotrophic

M: mixotrophic

FIGURES

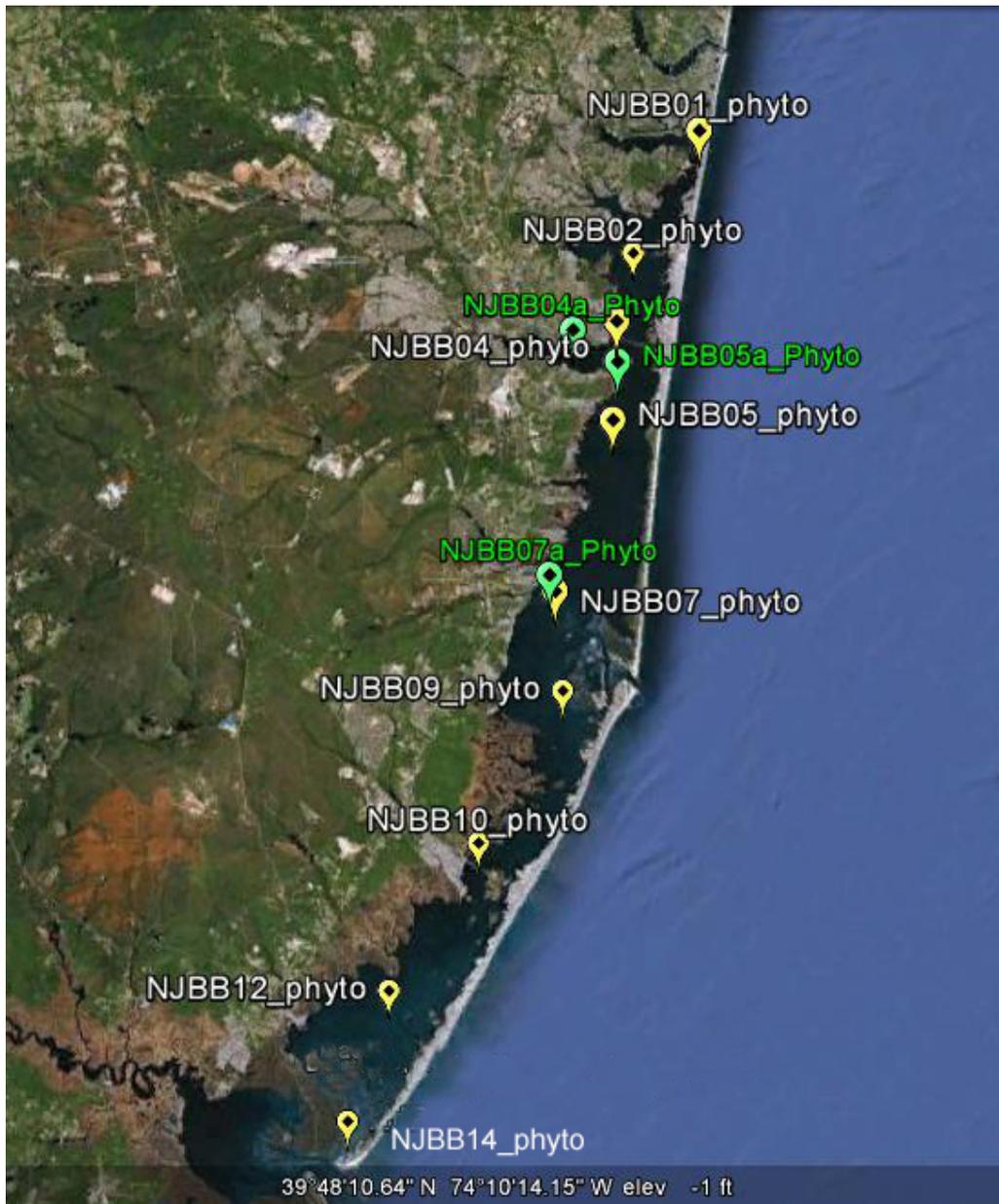


Fig. 1. Sites of phytoplankton collection from August 2011 to September 2012. The original nine sites are marked in yellow (note: BB14 is at the very bottom of the map). After May 2012, sites BB04, BB05 and BB07 were shifted to BB04a, BB05a and BB07a (in green). (See Table 1 for site descriptions).

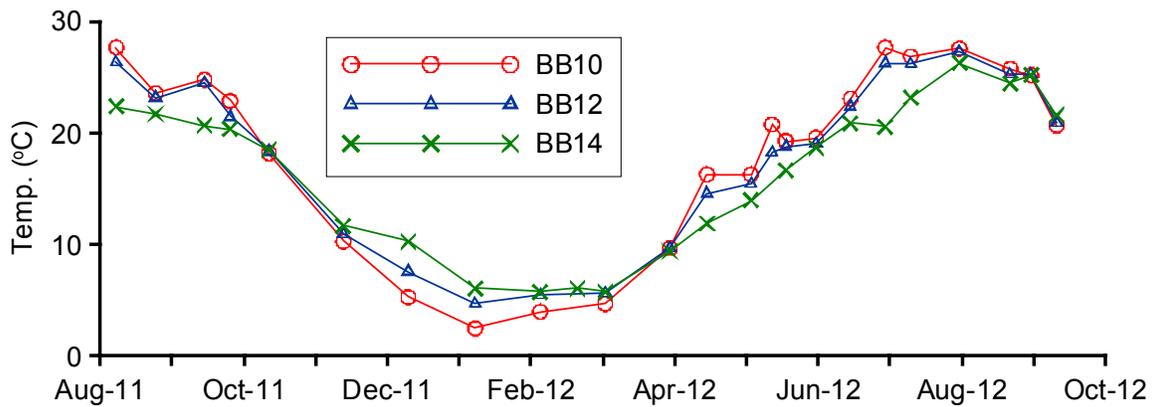
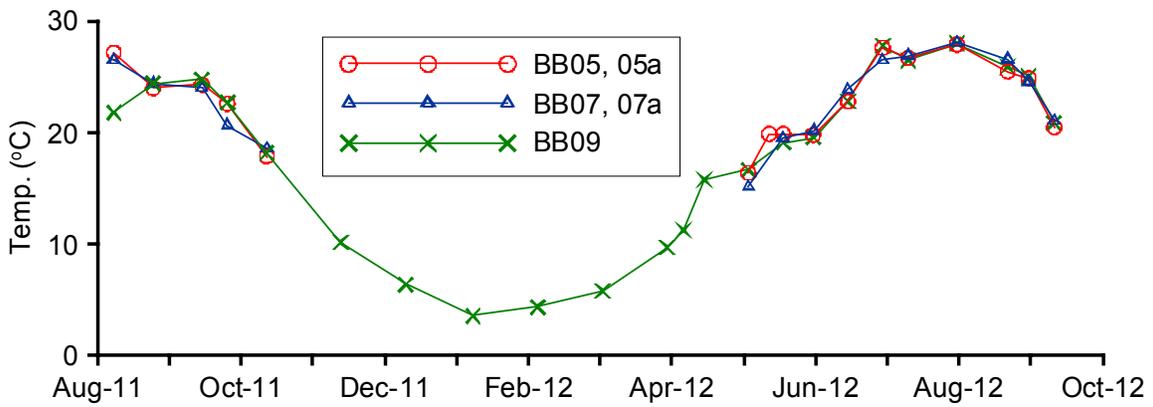
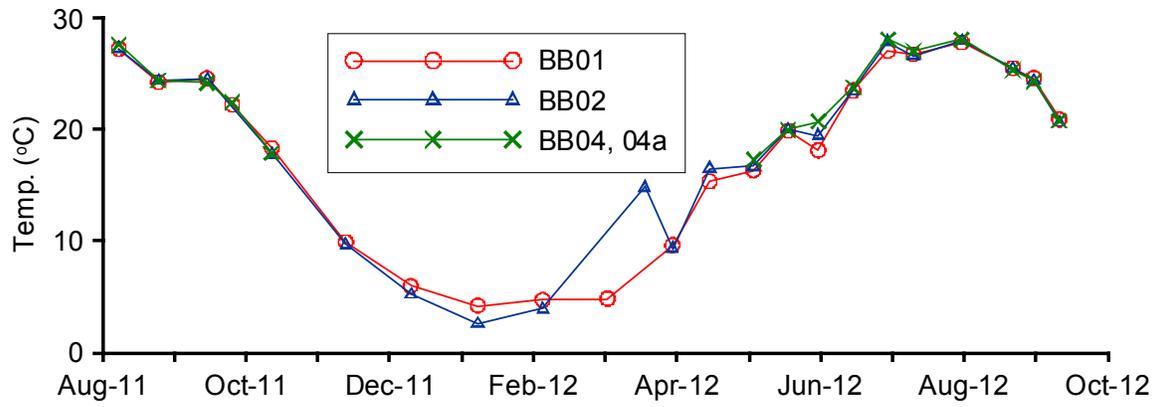


Fig. 2. Change of water temperature at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring, <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>.

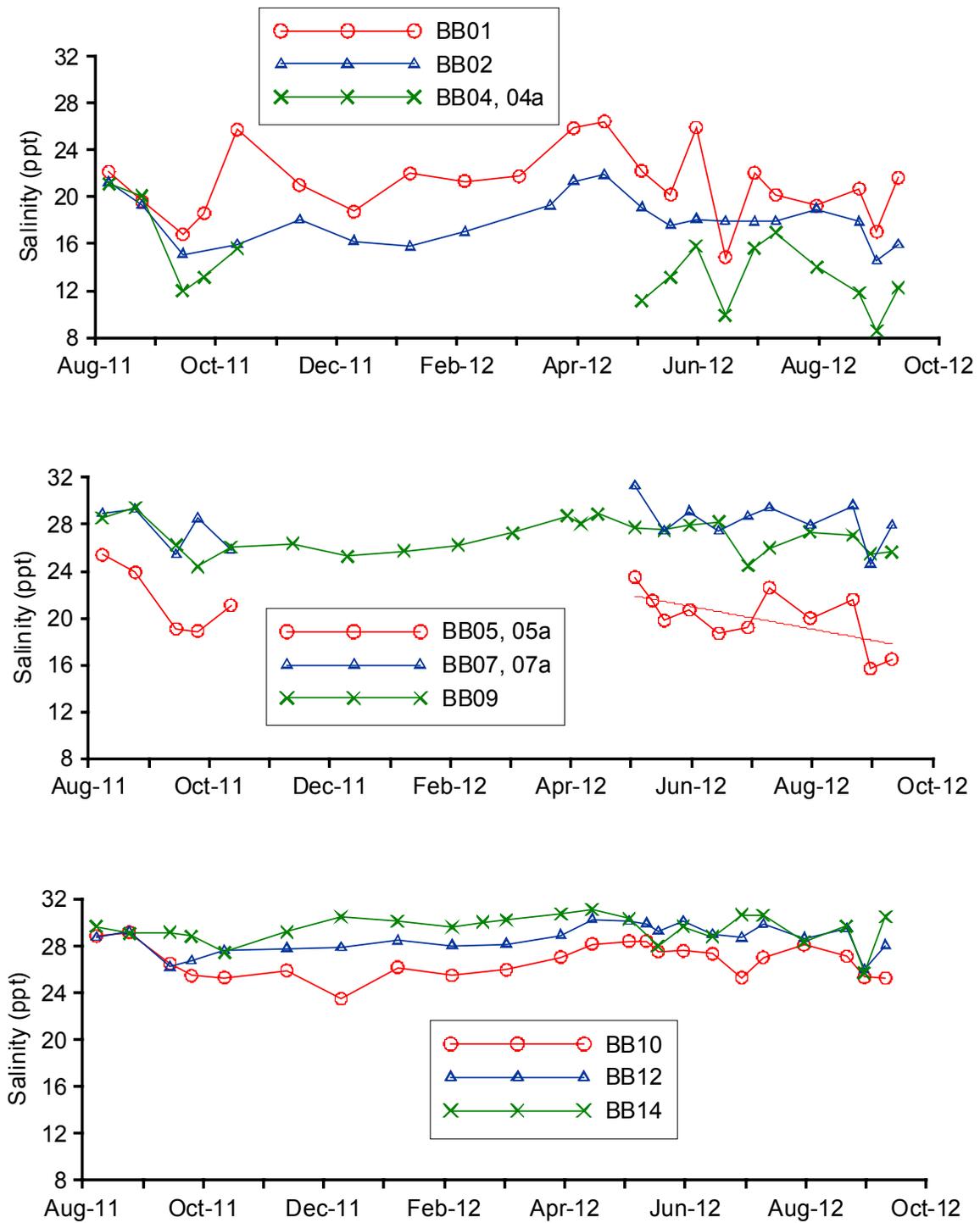


Fig. 3. Change of salinity at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring, <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>.

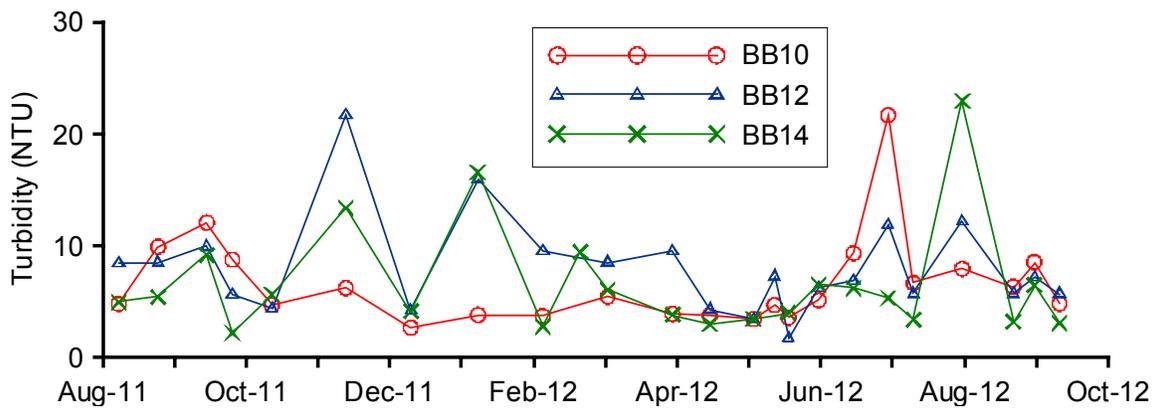
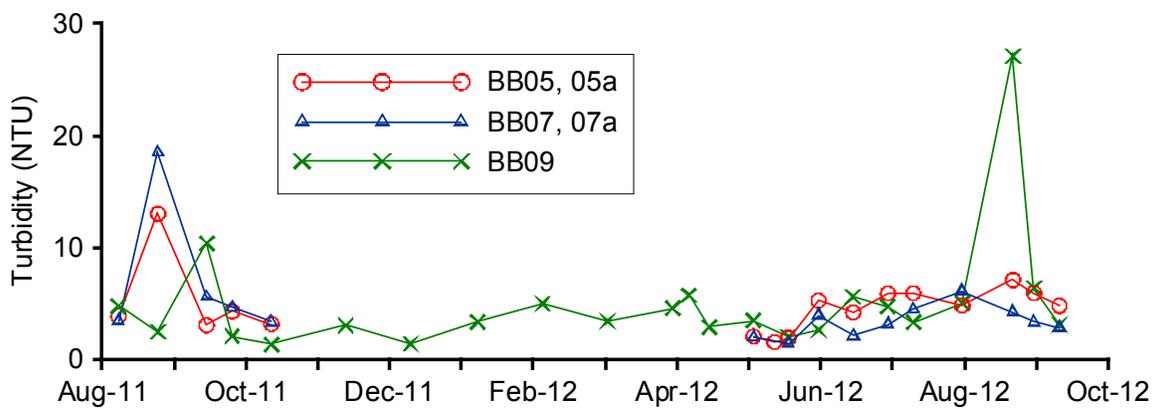
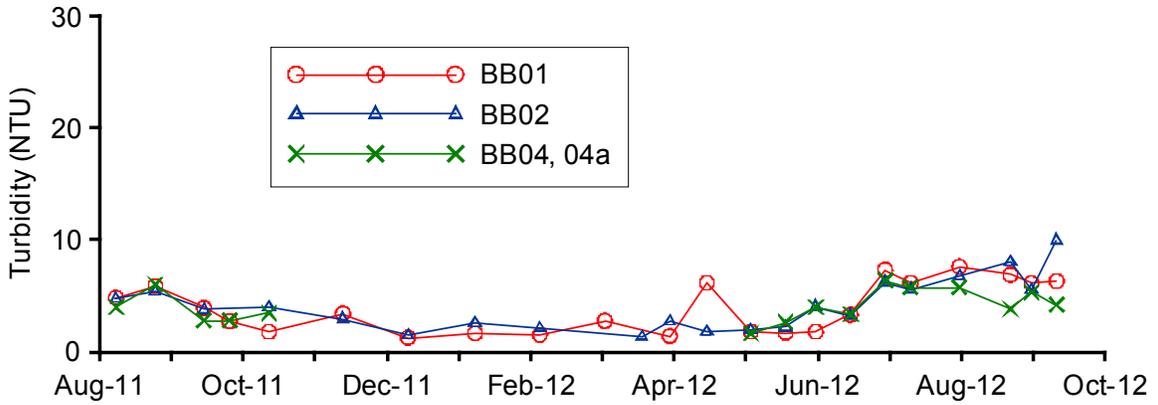


Fig. 4. Change of turbidity at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring, <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>.

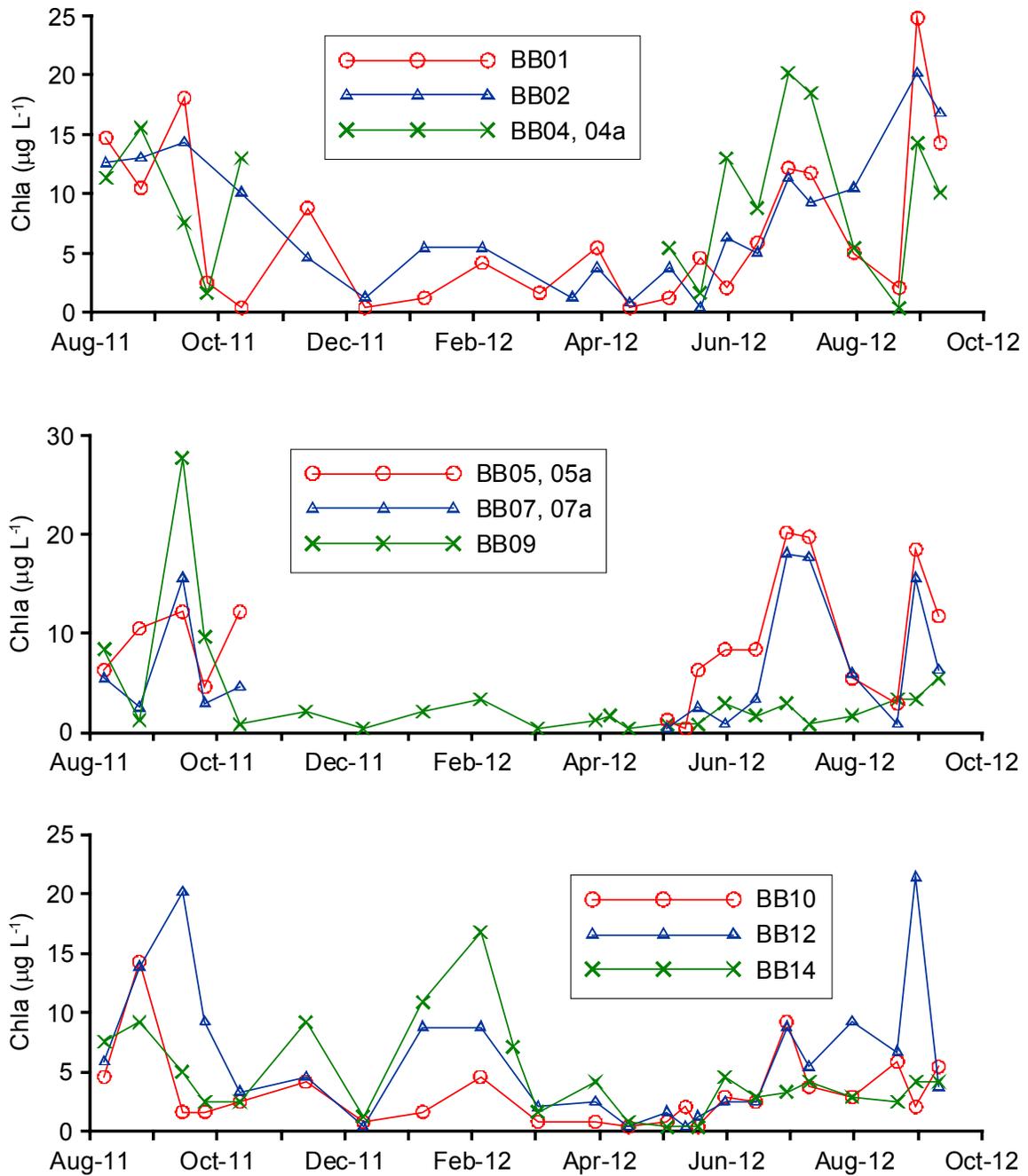


Fig. 5. Change of chlorophyll *a* at phytoplankton collection sites in BB-LEH from August 2011 to September 2012. Data from NJDEP water quality monitoring, <http://www.nj.gov/dep/barnegatbay/bbmapviewer.htm>.

Site BB01

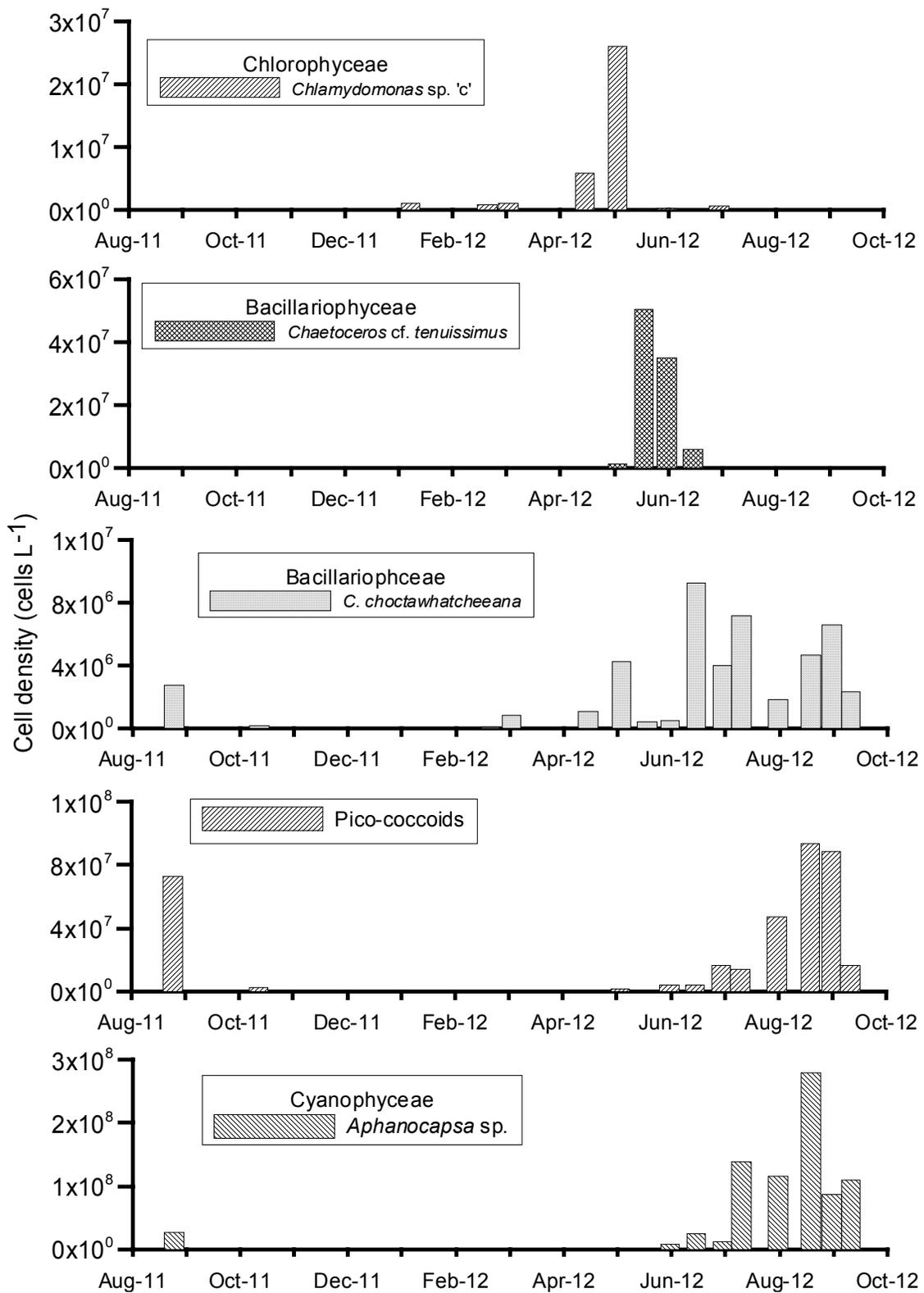


Fig. 6. Abundance and seasonal changes of some dominant species at site BB01 from August 2011 to September 2012.

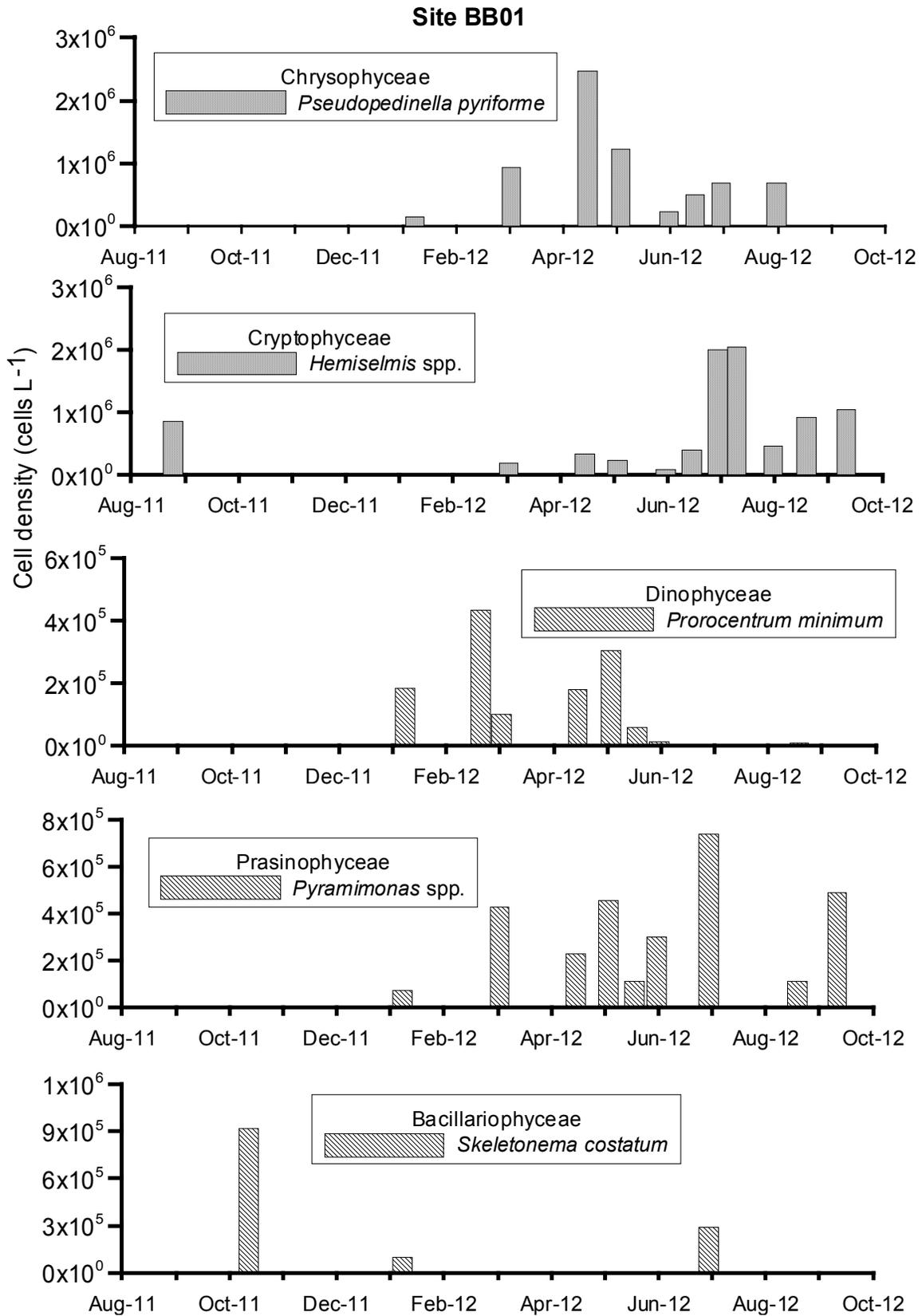


Fig. 6 (Cont.). Abundance and seasonal changes of some dominant species at site BB01 from August 2011 to September 2012.

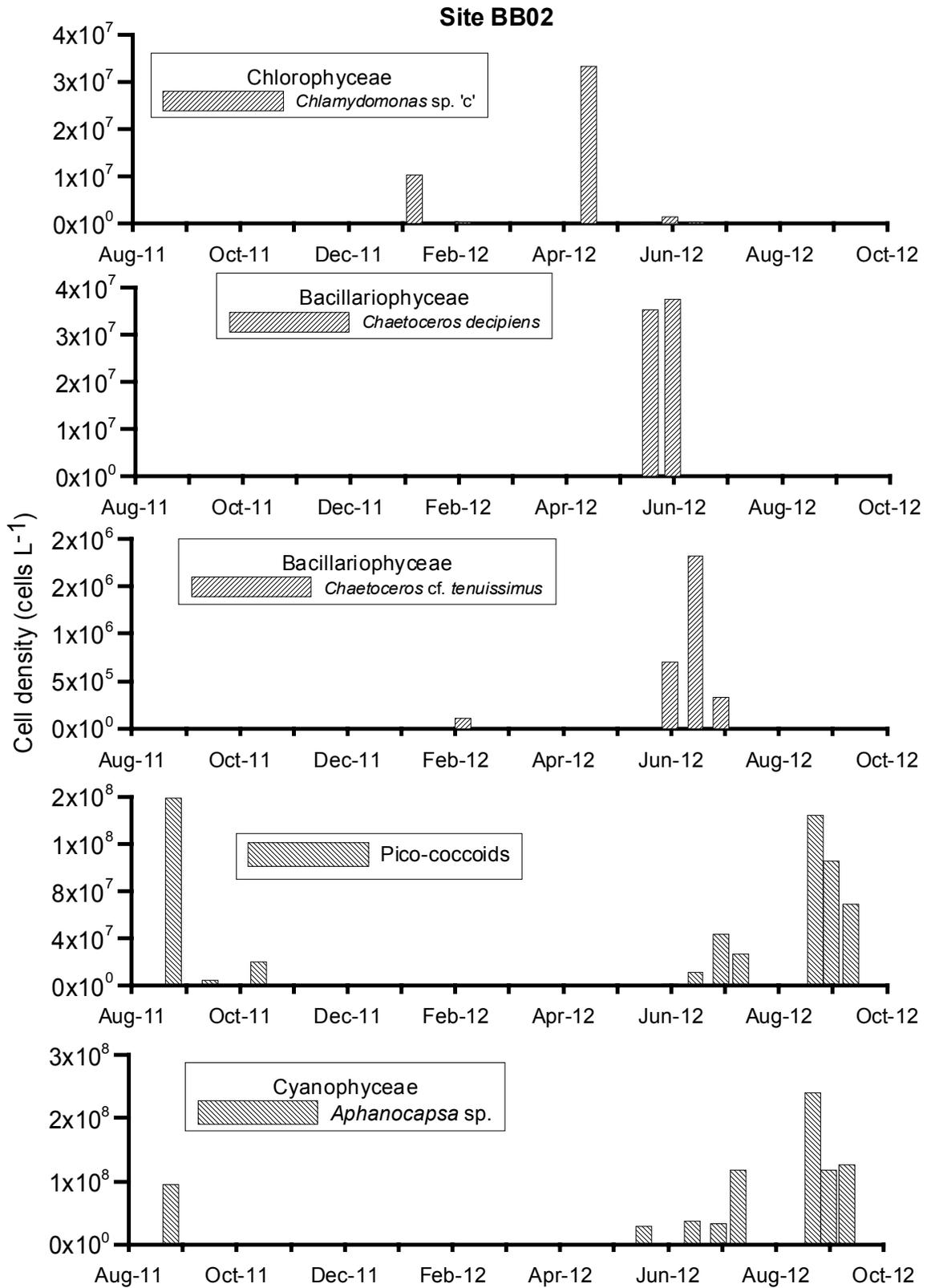


Fig. 7. Abundance and seasonal changes of some dominant species at site BB02 from August 2011 to September 2012.

Site BB02

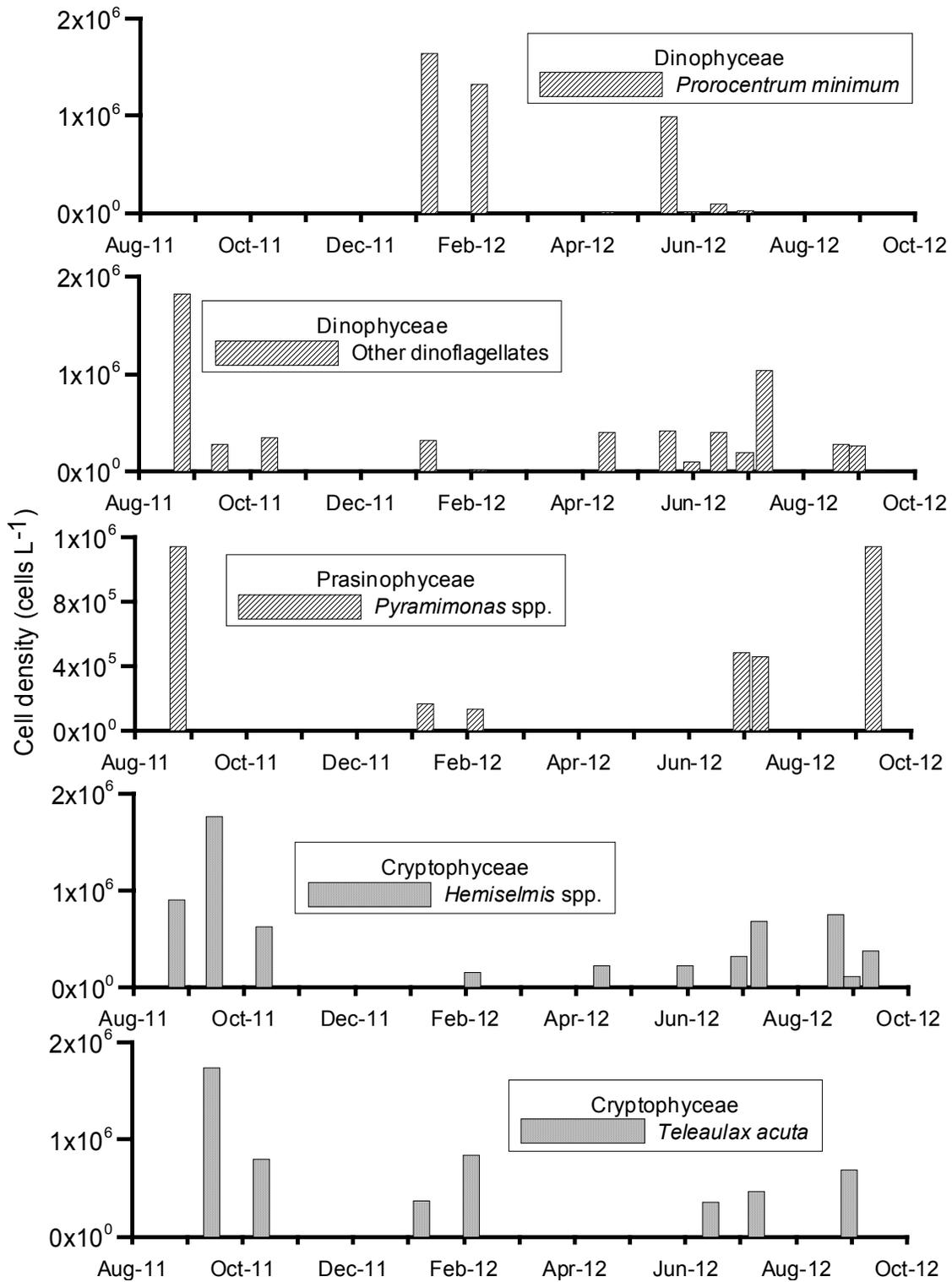


Fig. 7 (Cont.). Abundance and seasonal changes of some dominant species at site BB02 from August 2011 to September 2012.

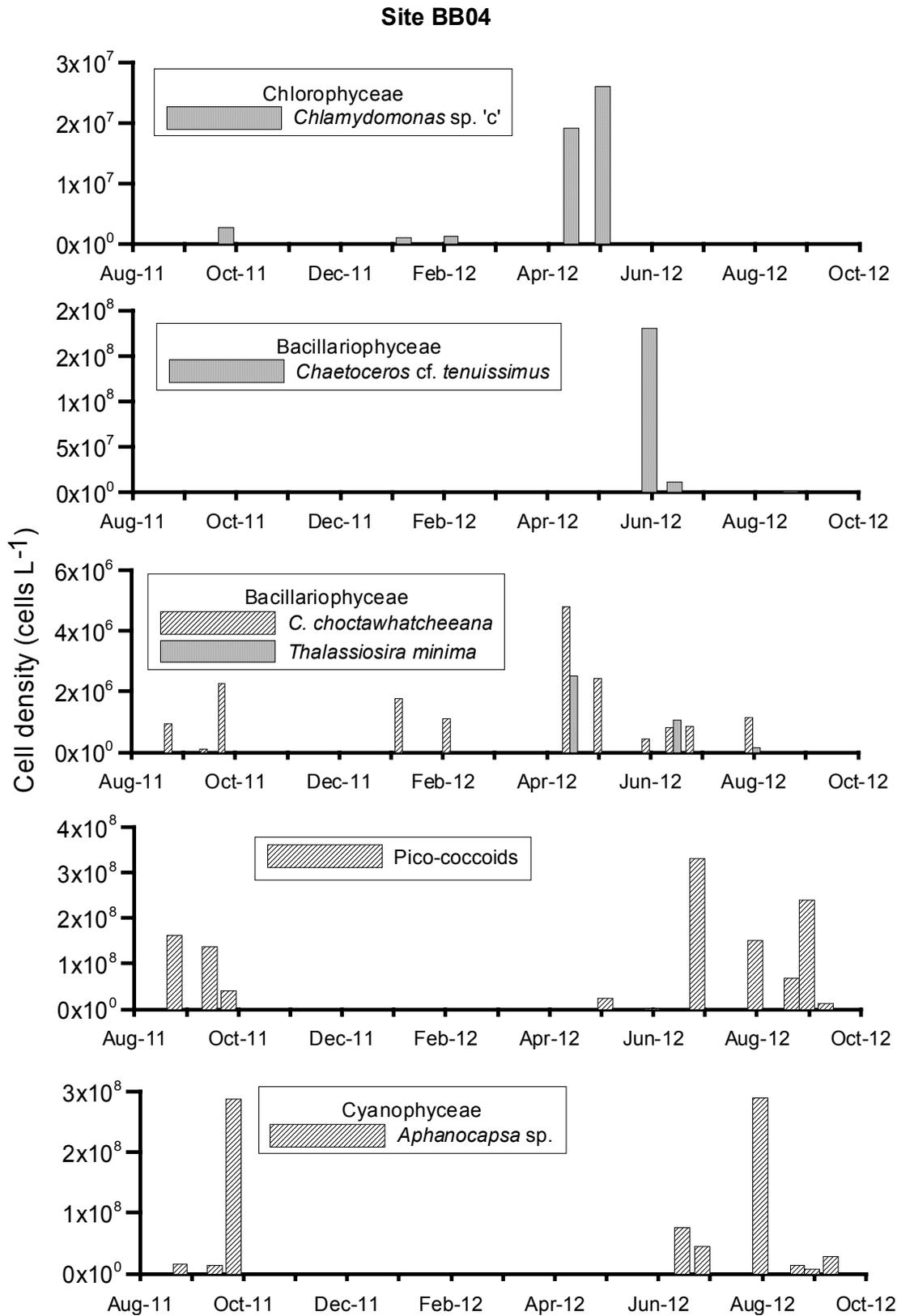


Fig. 8. Abundance and seasonal changes of some dominant species at site BB04 (BB04a) from August 2011 to September 2012.

Site BB04

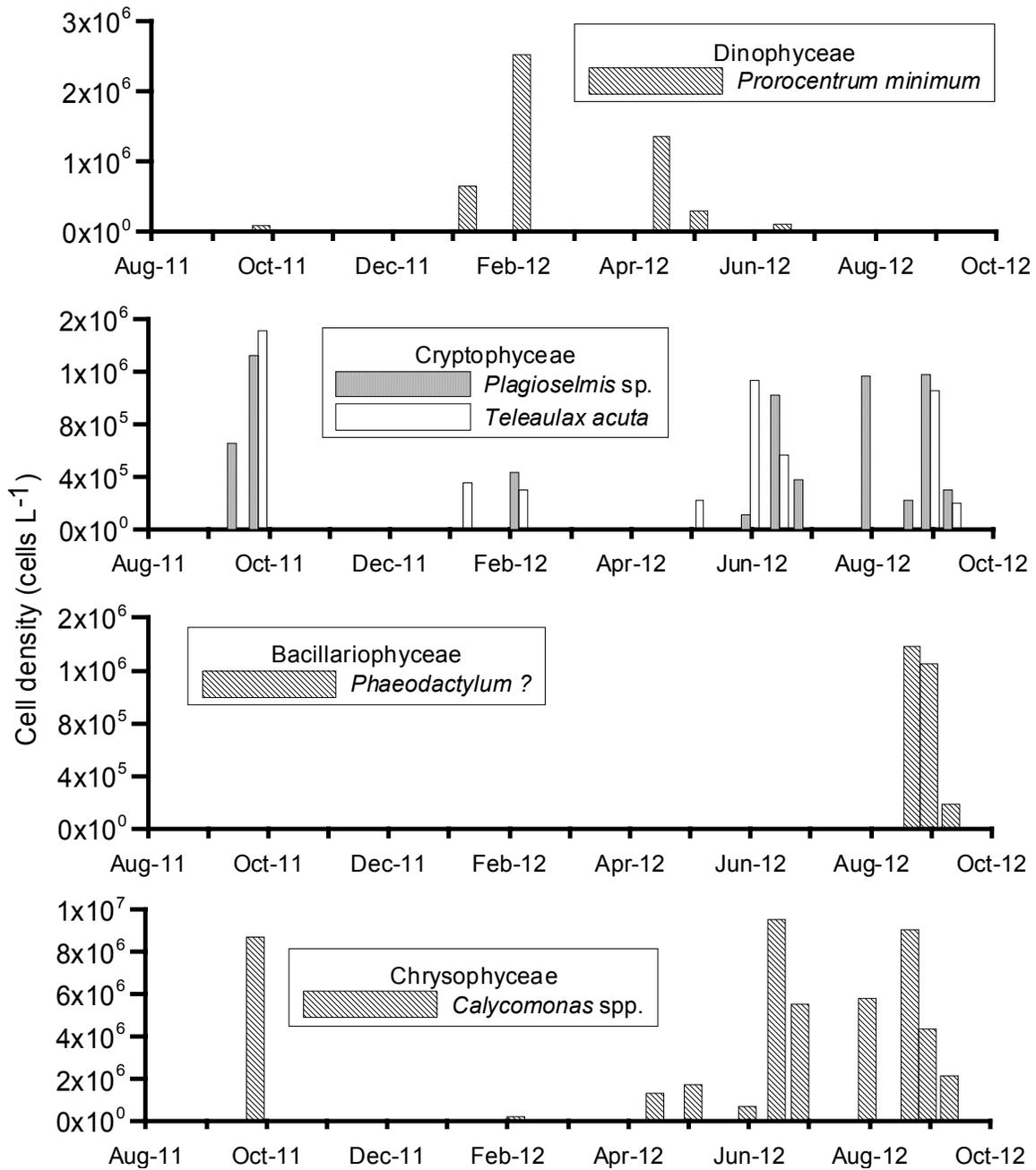


Fig. 8 (Cont.). Abundance and seasonal changes of some dominant species at site BB04 (BB04a) from August 2011 to September 2012.

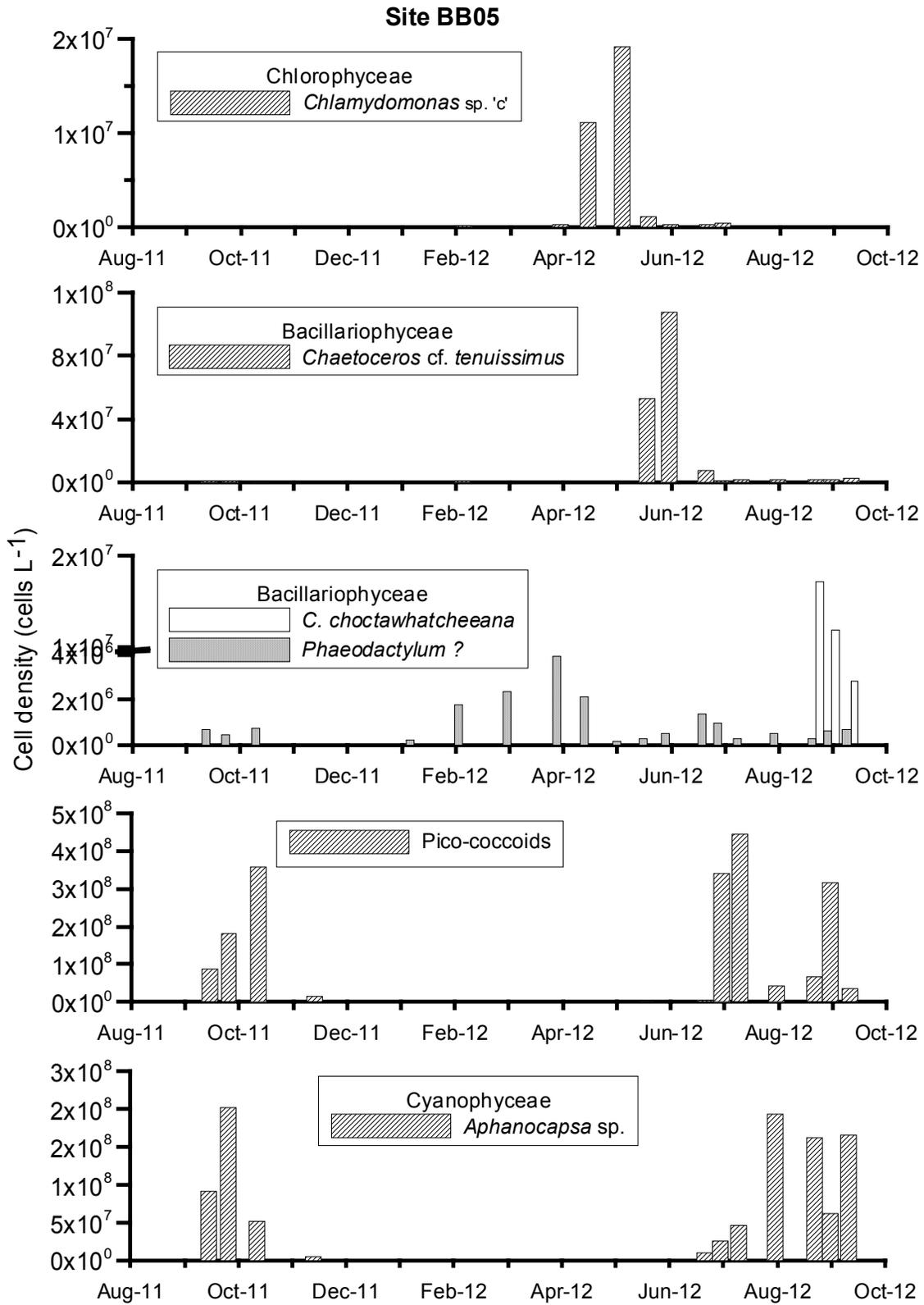


Fig. 9. Abundance and seasonal changes of some dominant species at site BB05 (BB05a) from August 2011 to September 2012. Note: Y-axis in panel 3 break from 4×10^6 to 1×10^7 .

Site BB05

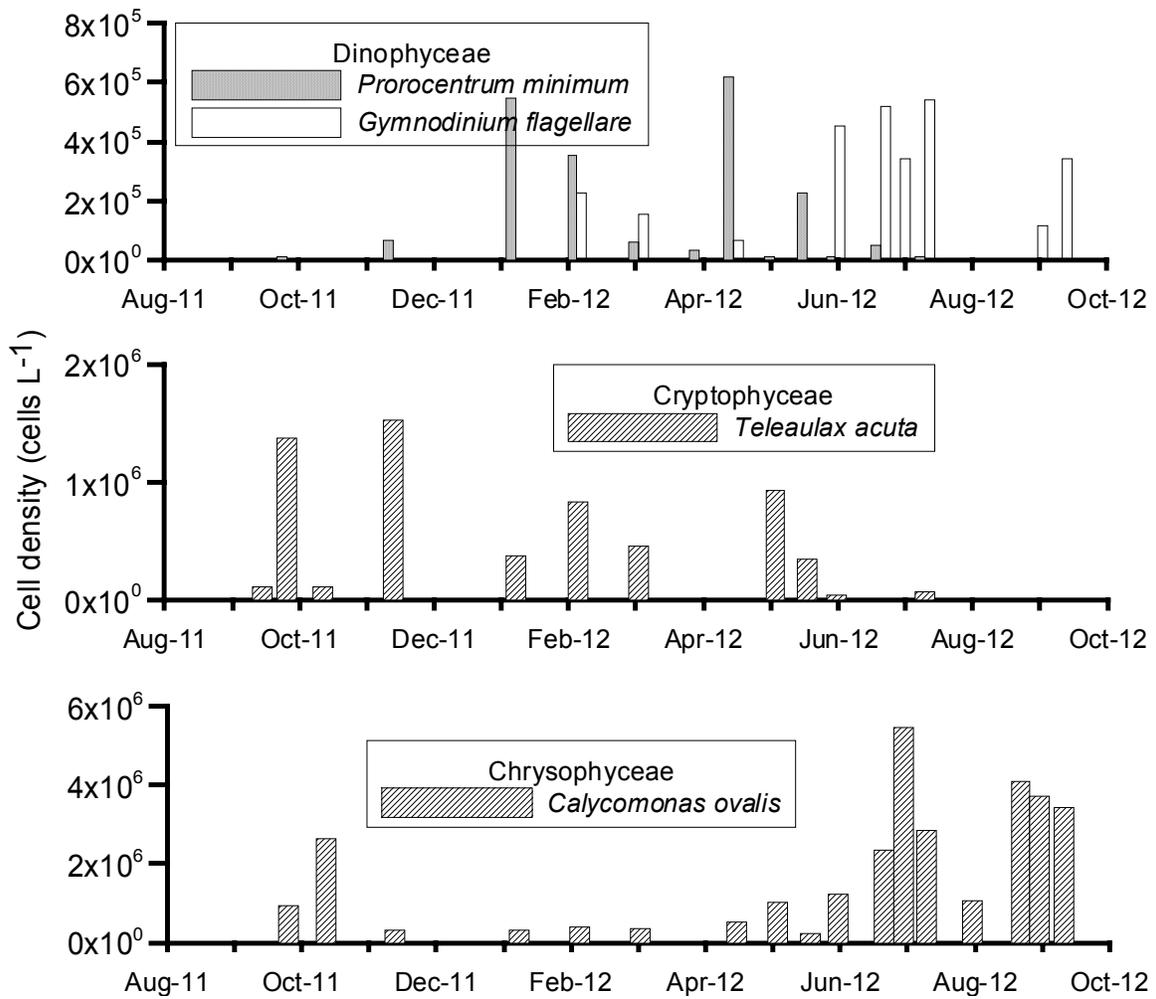


Fig.9 (Cont.). Abundance and seasonal changes of some dominant species at site BB05 (BB05a) from August 2011 to September 2012.

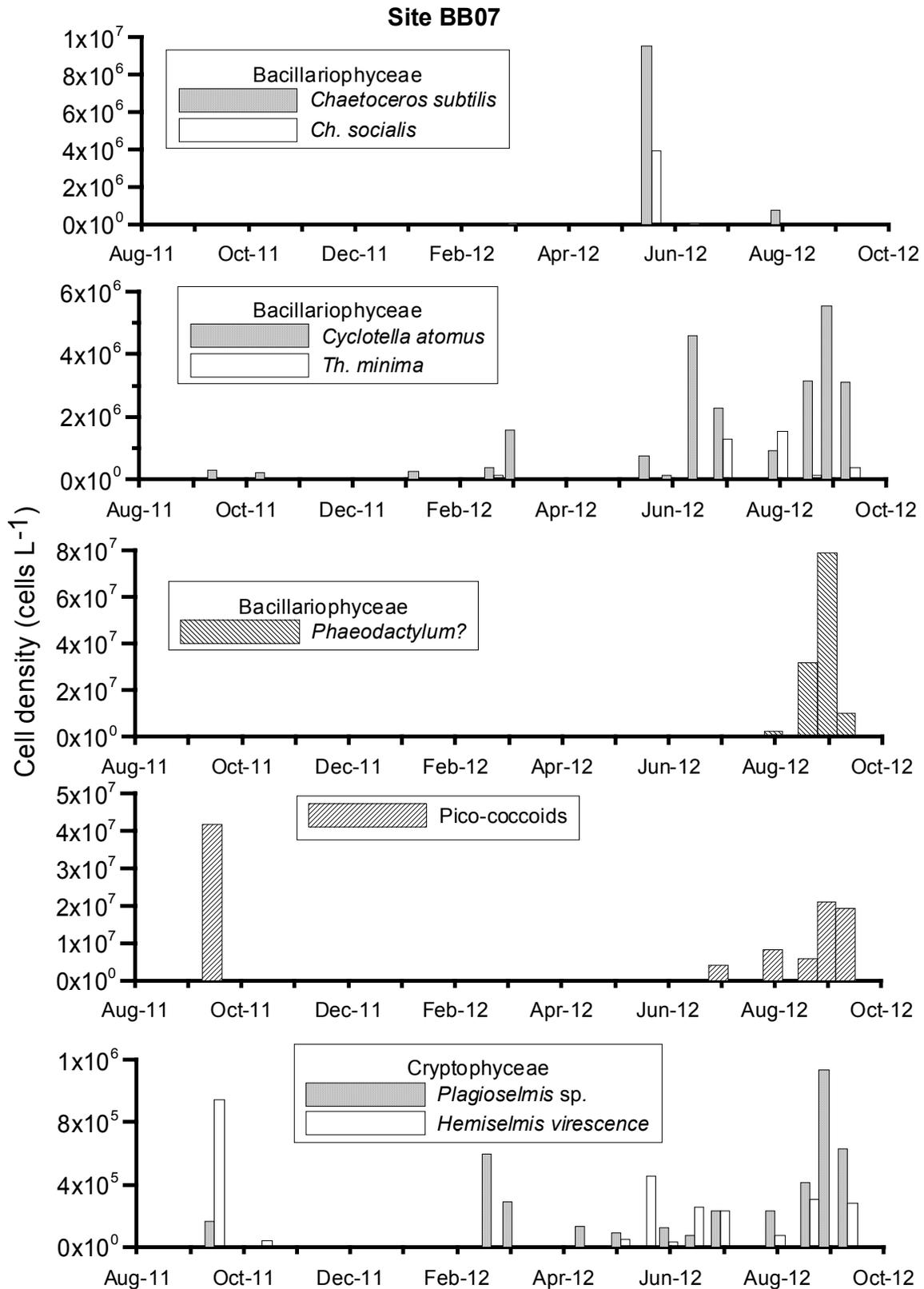


Fig. 10. Abundance and seasonal changes of some dominant species at site BB07 (BB07a) from August 2011 to September 2012.

Site BB07

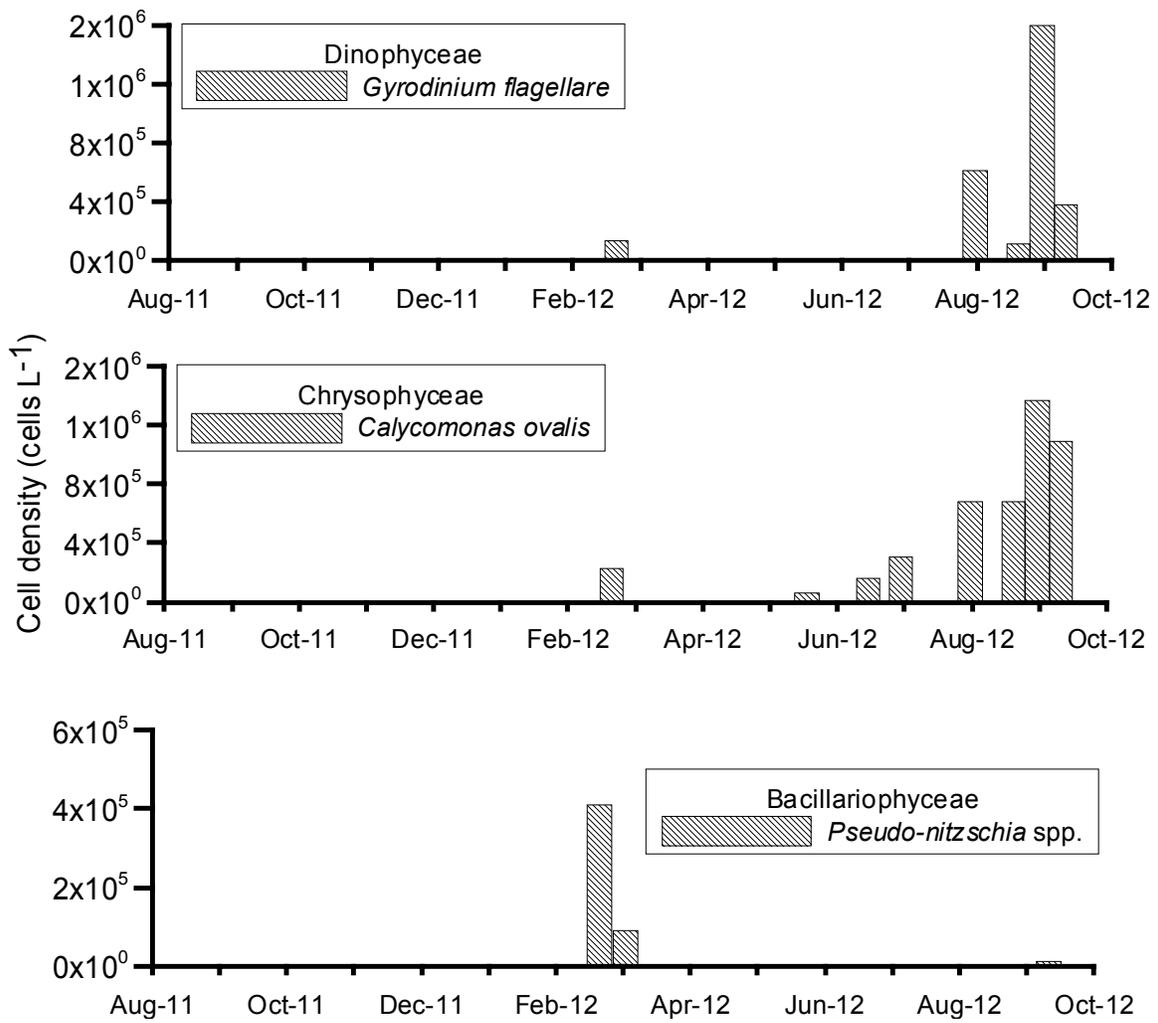


Fig. 10 (Cont.). Abundance and seasonal changes of some dominant species at site BB07 (BB07a) from August 2011 to September 2012.

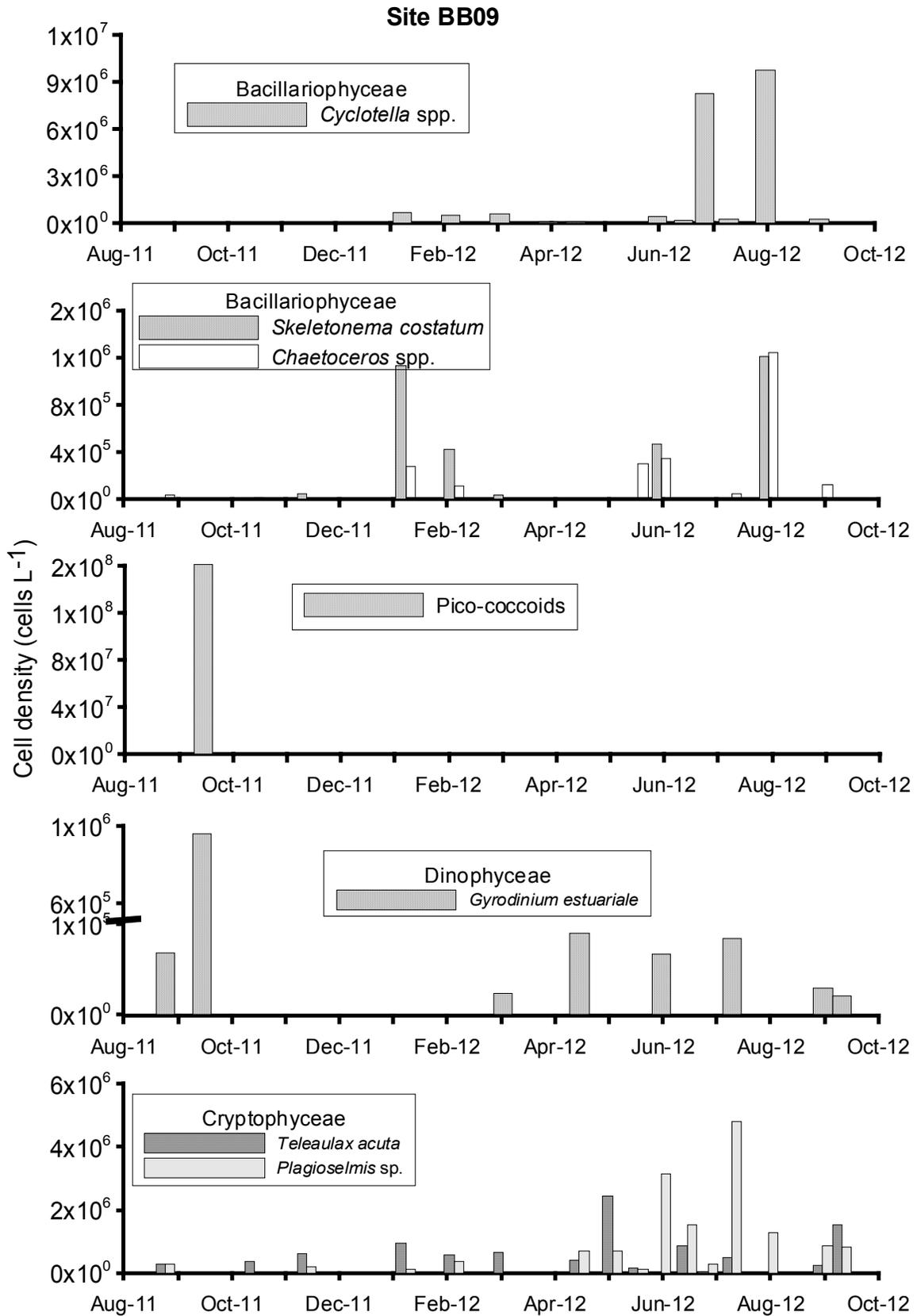


Fig. 11. Abundance and seasonal changes of some dominant species at site BB09 from August 2011 to September 2012. Note: Y-axis in panel 4 break from 1×10^5 to 5×10^5 .

Site BB12

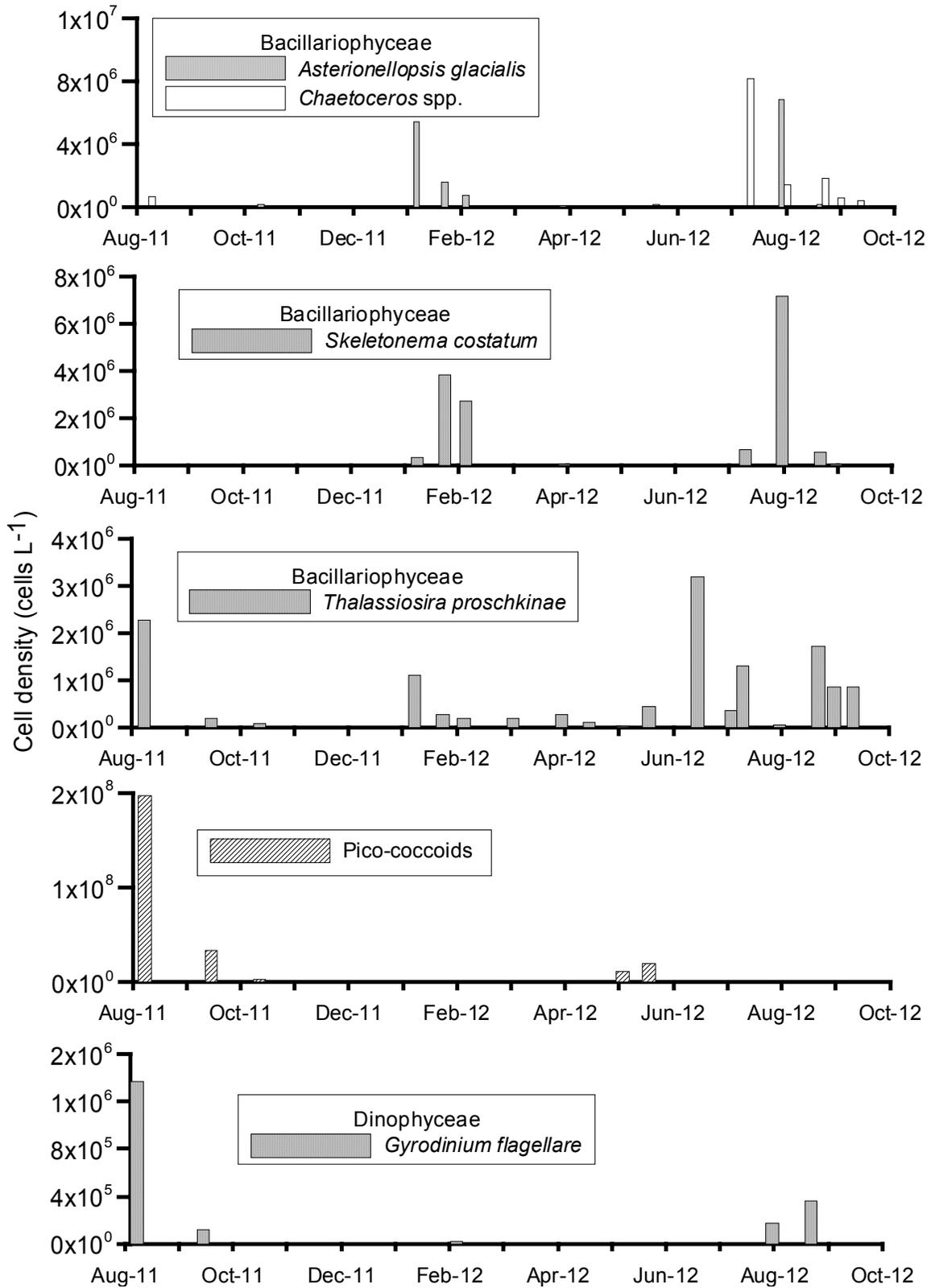


Fig. 12. Abundance and seasonal changes of some dominant species at site BB12 from August 2011 to September 2012.

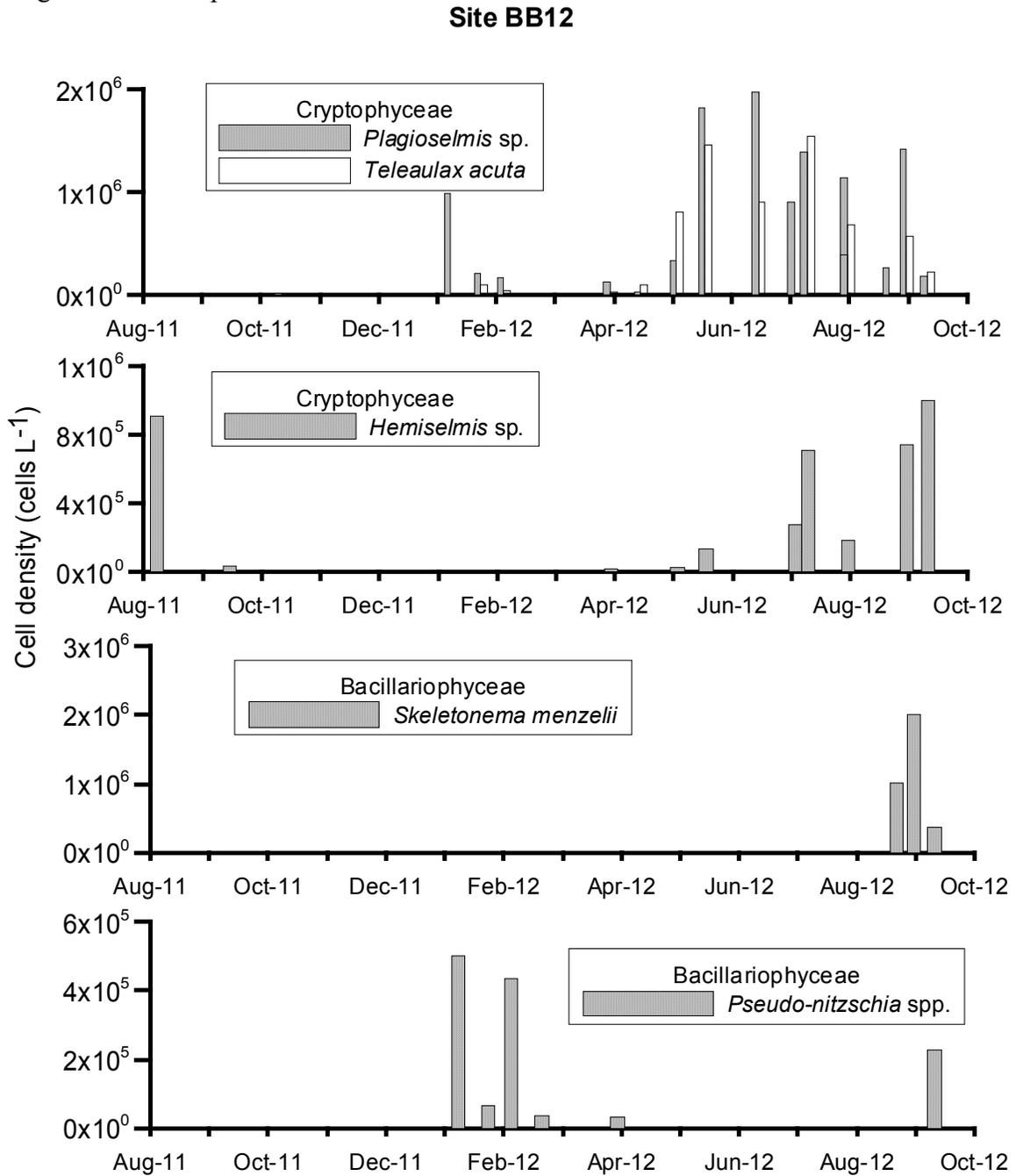


Fig. 12 (Cont.). Abundance and seasonal changes of some dominant species at site BB12 from August 2011 to September 2012.

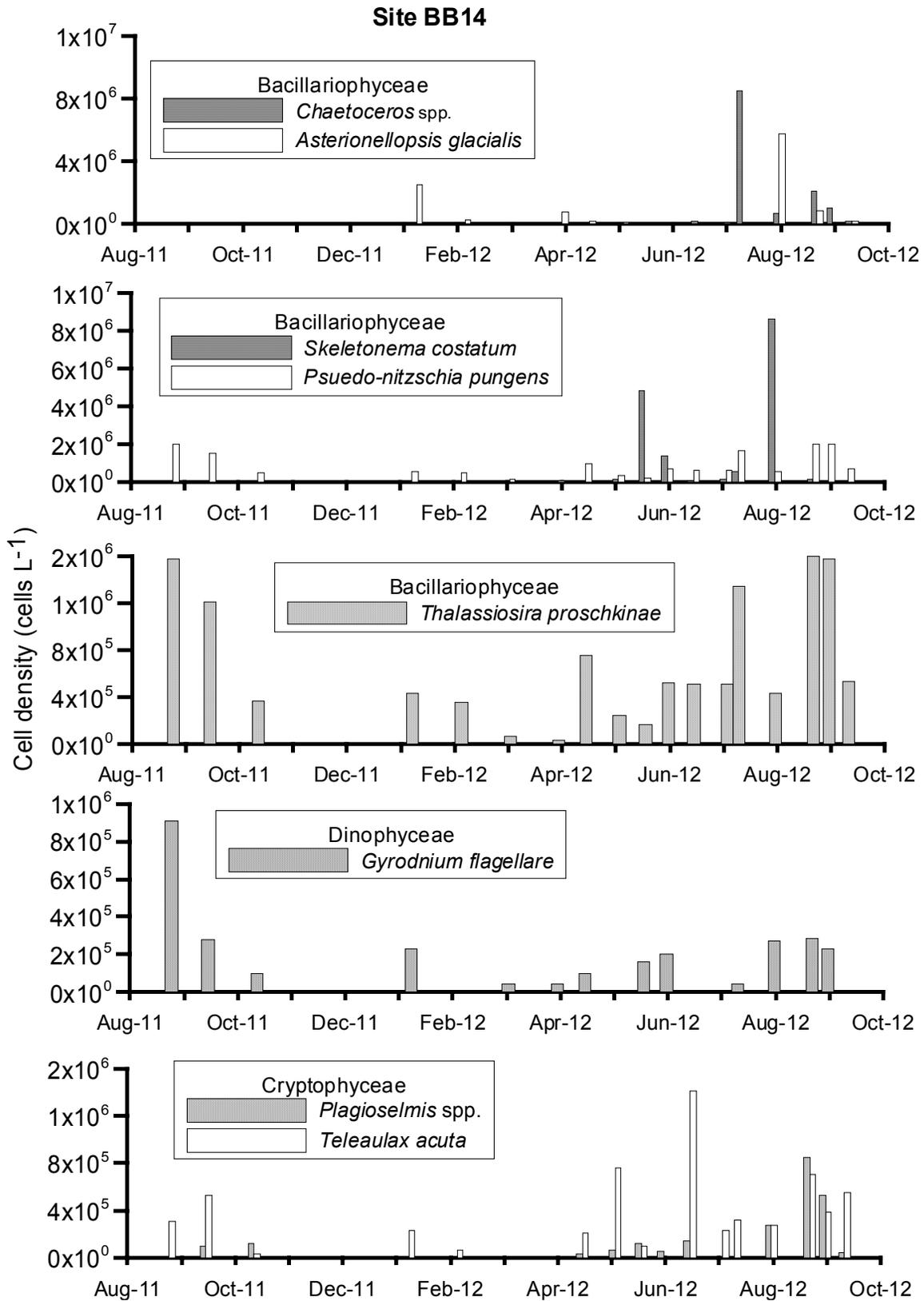


Fig. 13. Abundance and seasonal changes of some dominant species at site BB14 from August 2011 to September 2012.

Site BB14

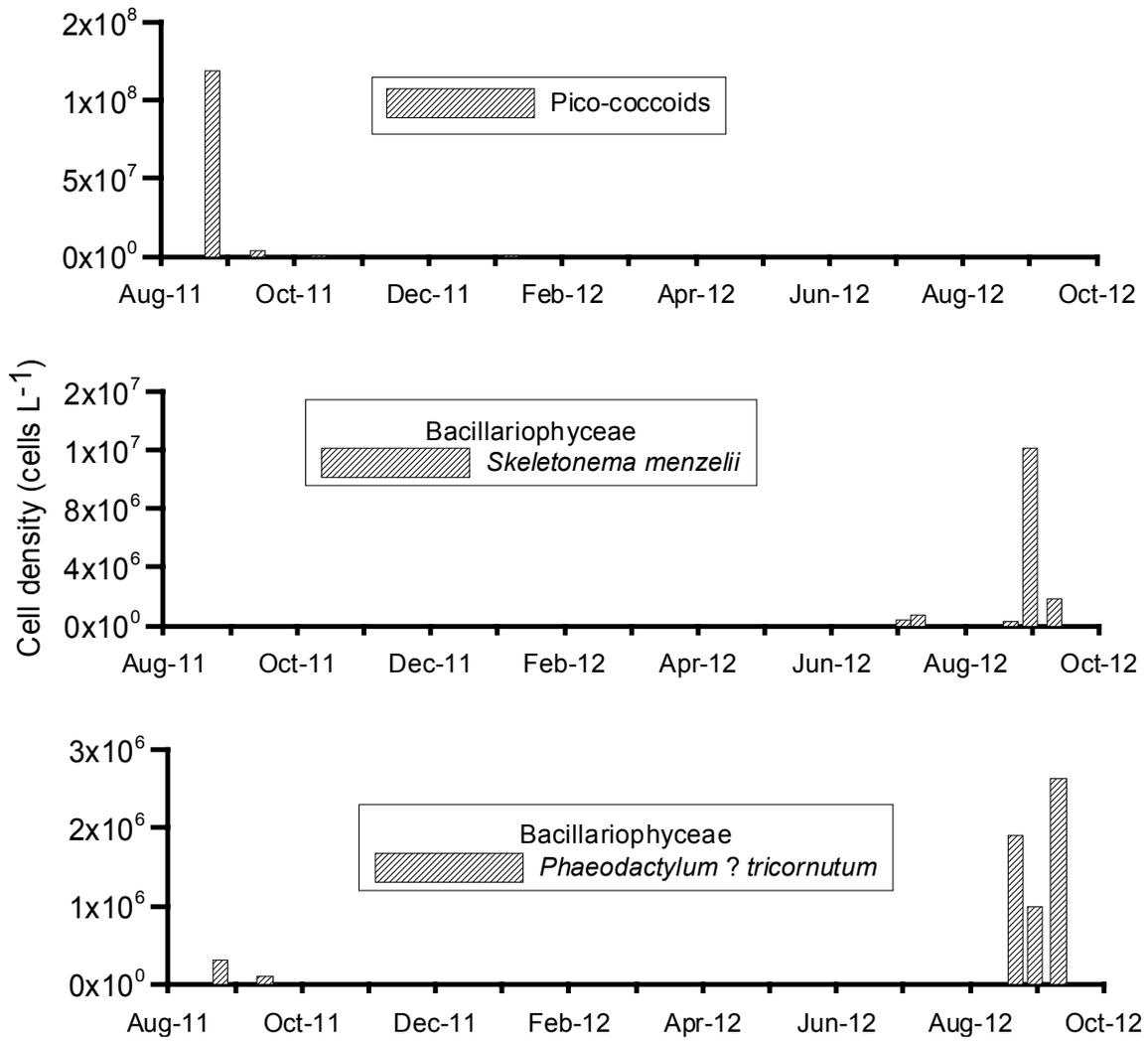


Fig. 13 (Cont.). Abundance and seasonal changes of some dominant species at site BB14 from August 2011 to September 2012.

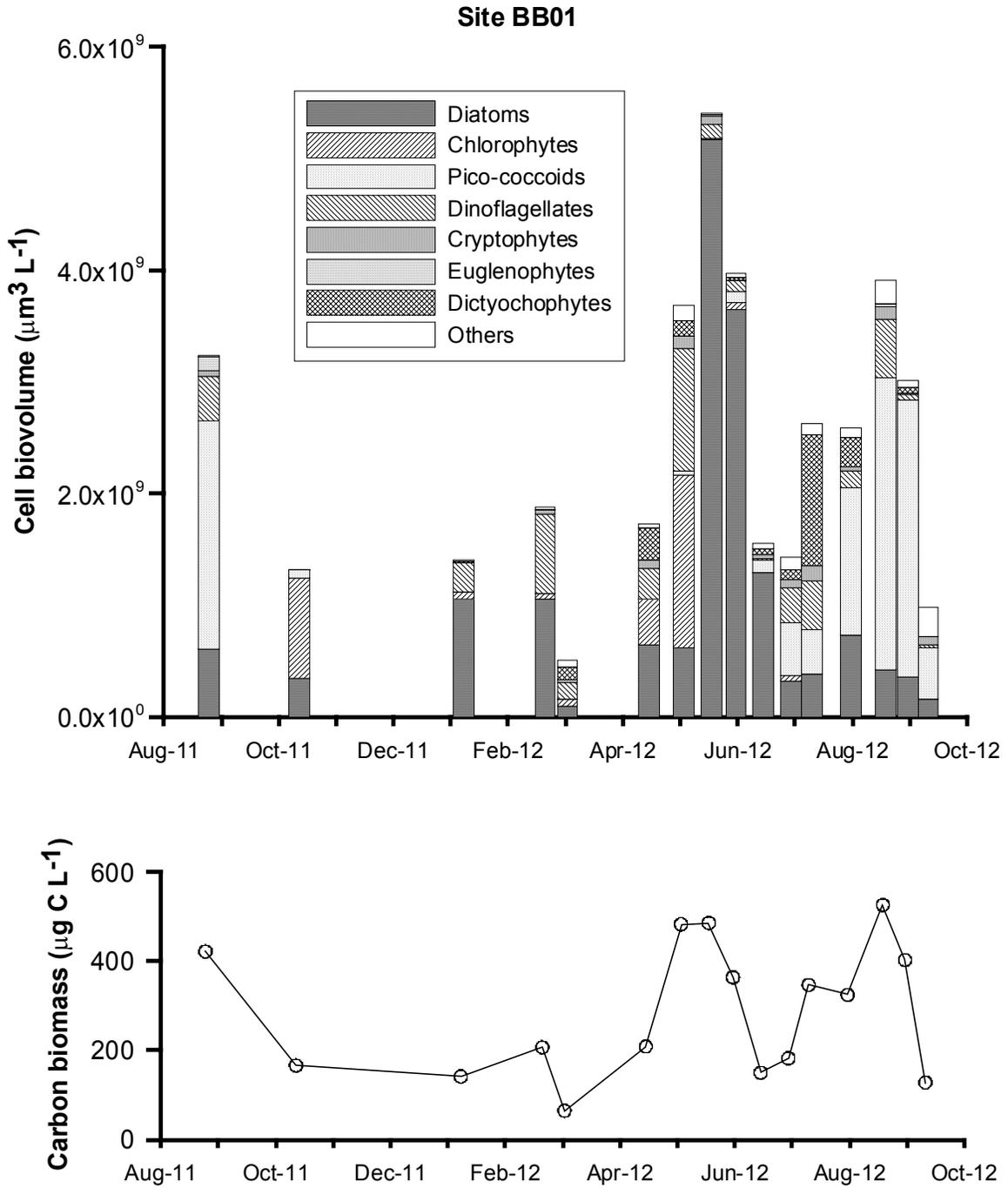


Fig. 14. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB01 from August 2011 to September 2012.

Site BB02

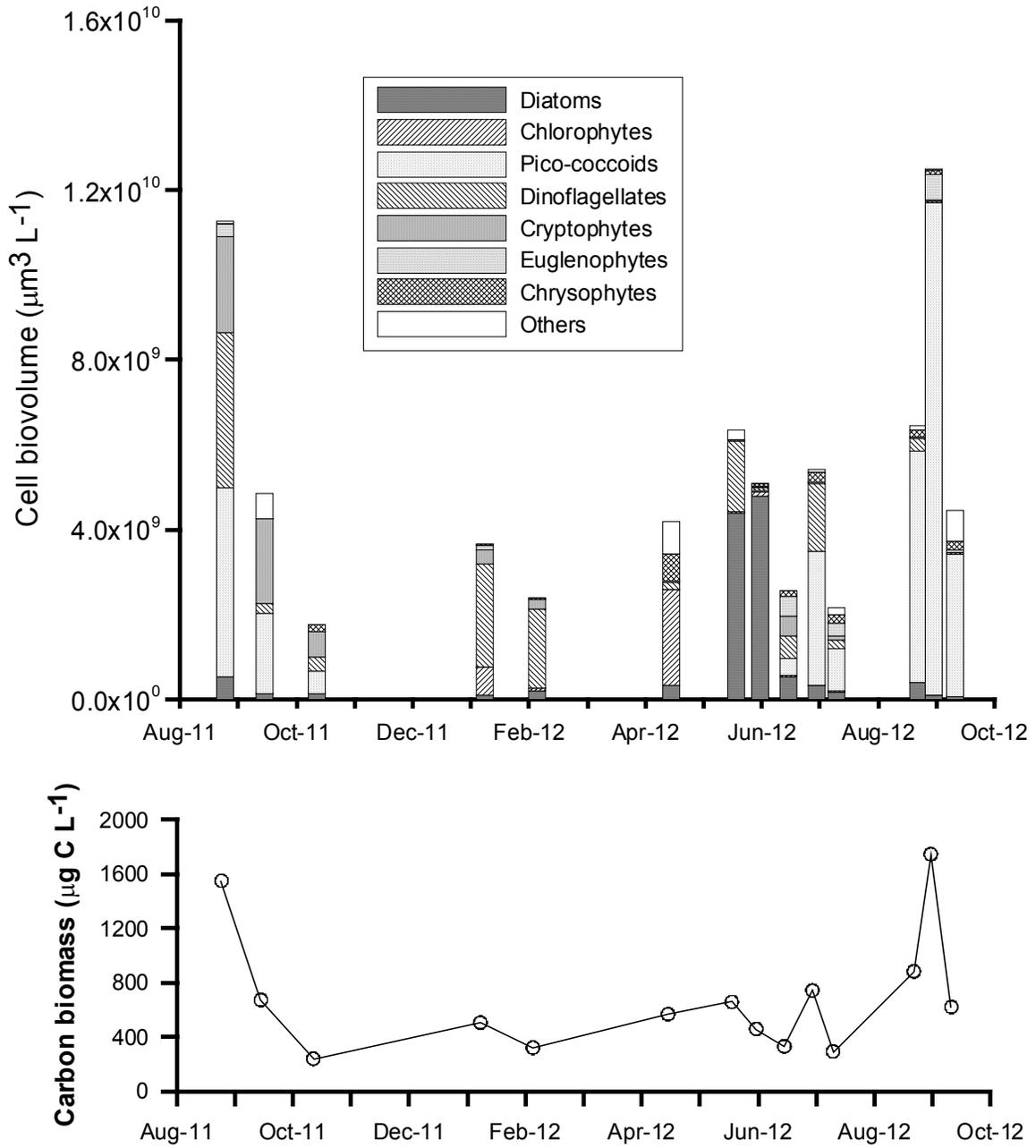


Fig. 15. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB02 from August 2011 to September 2012.

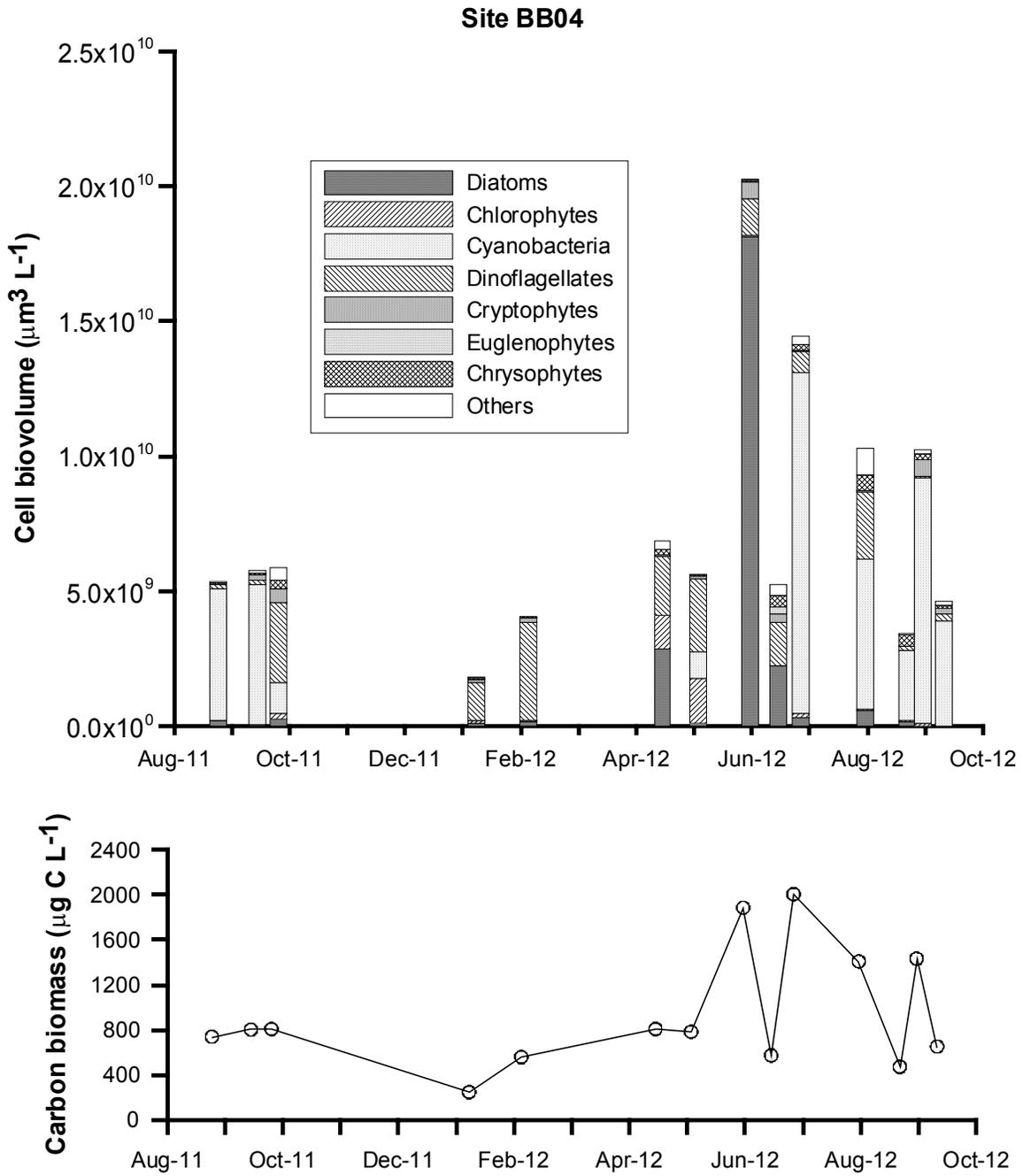


Fig. 16. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB04 from August 2011 to September 2012.

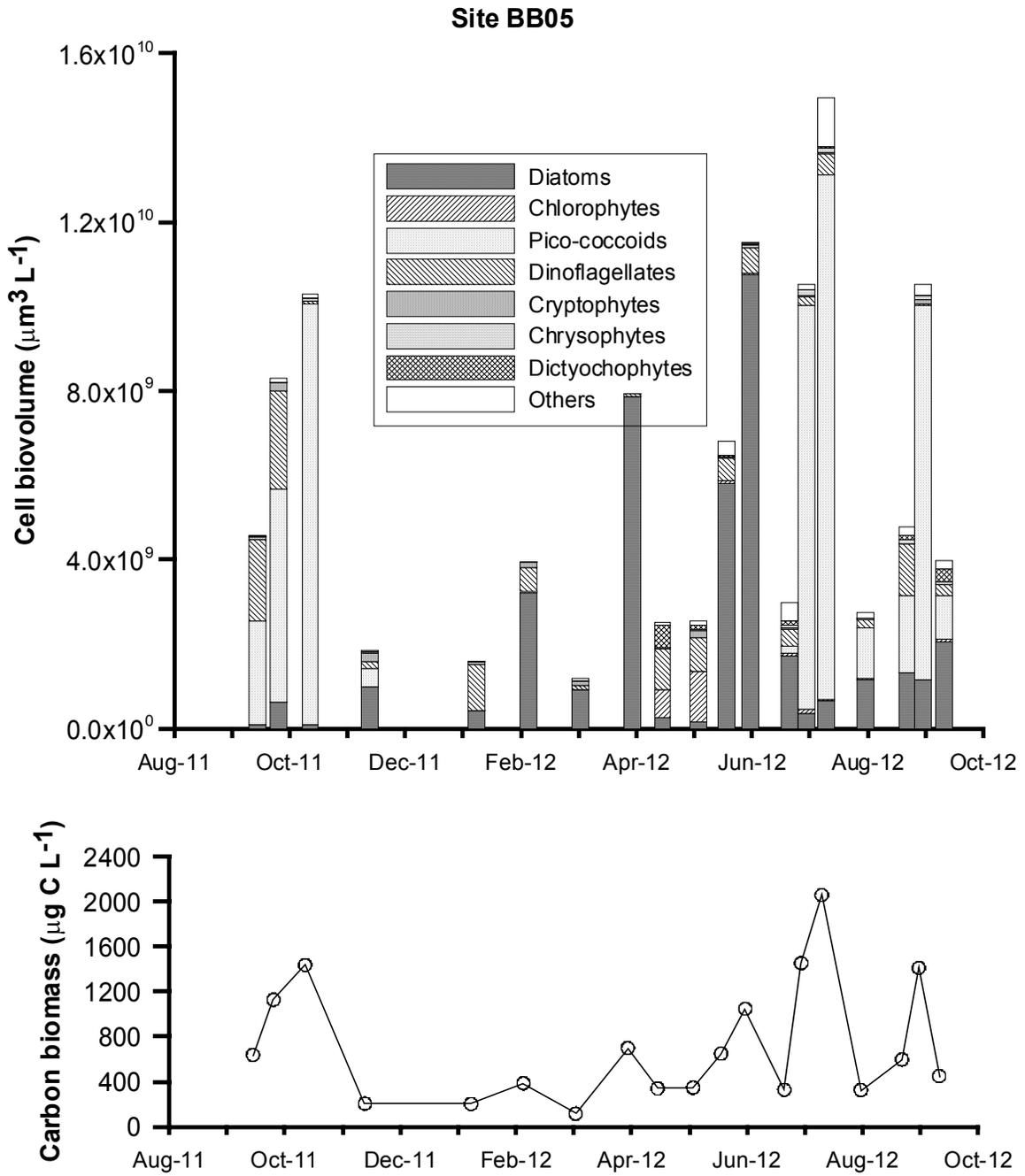


Fig. 17. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB05 from August 2011 to September 2012.

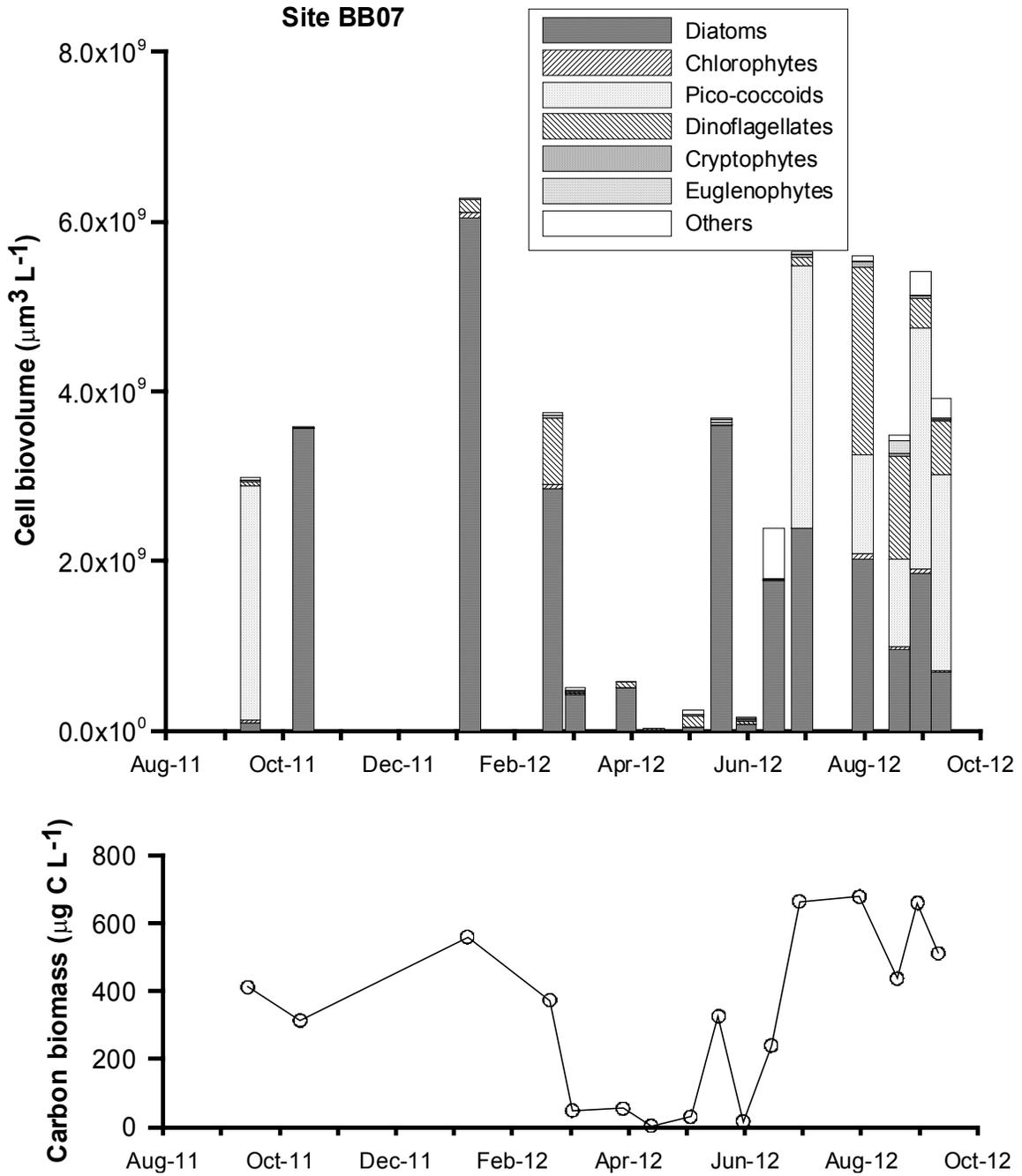


Fig. 18. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB07 from August 2011 to September 2012.

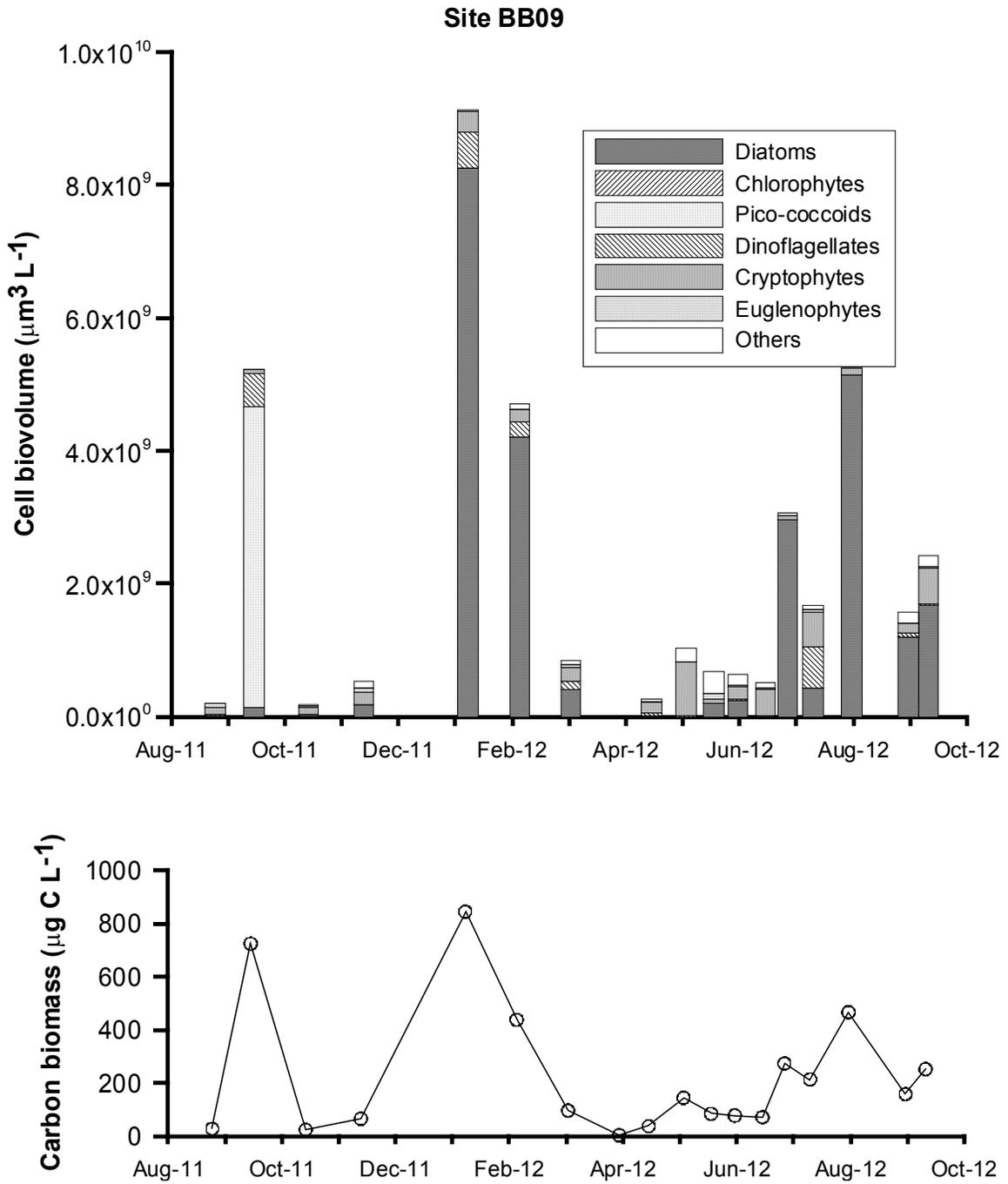


Fig. 19. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB09 from August 2011 to September 2012.

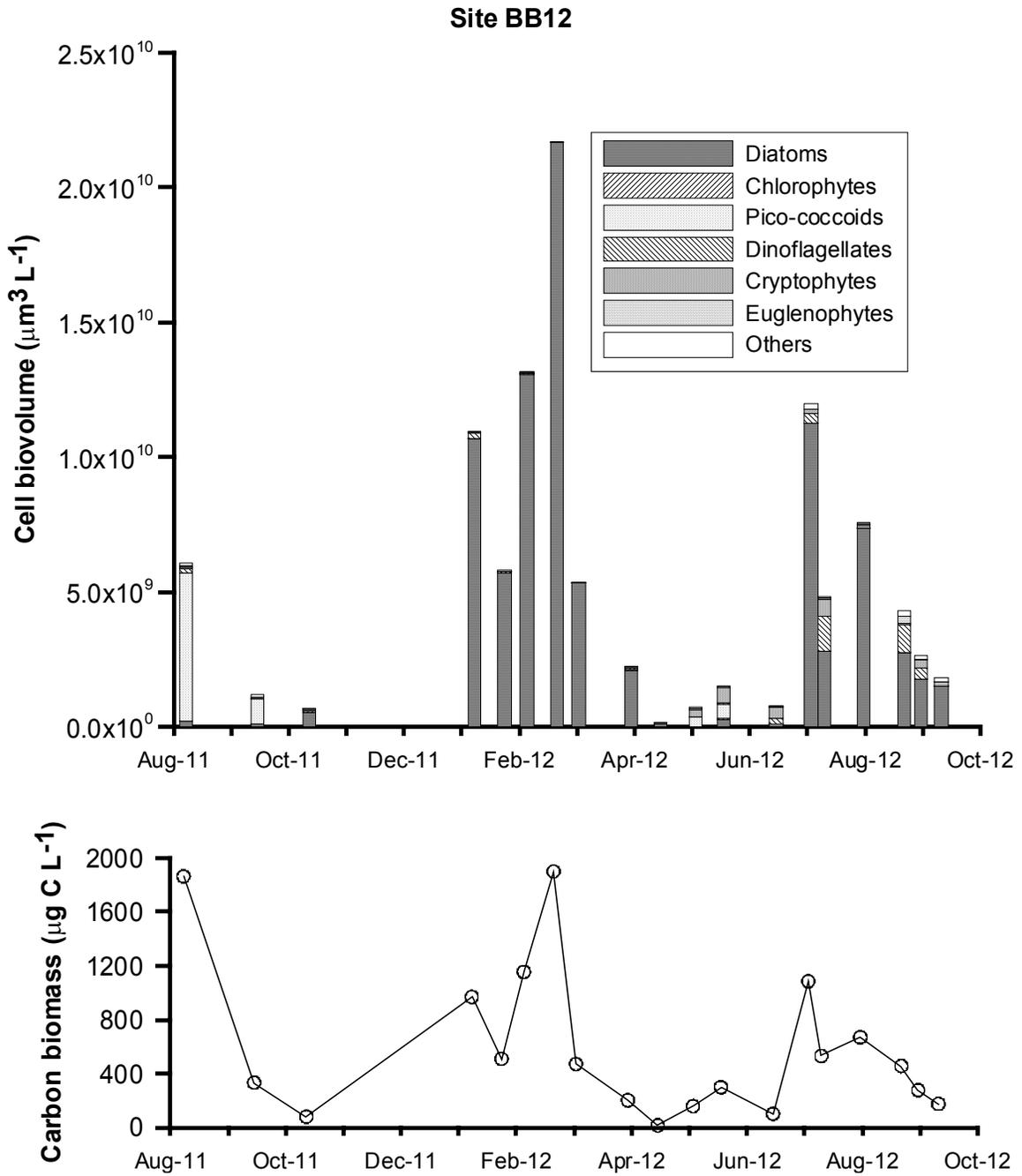


Fig. 20. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB12 from August 2011 to September 2012.

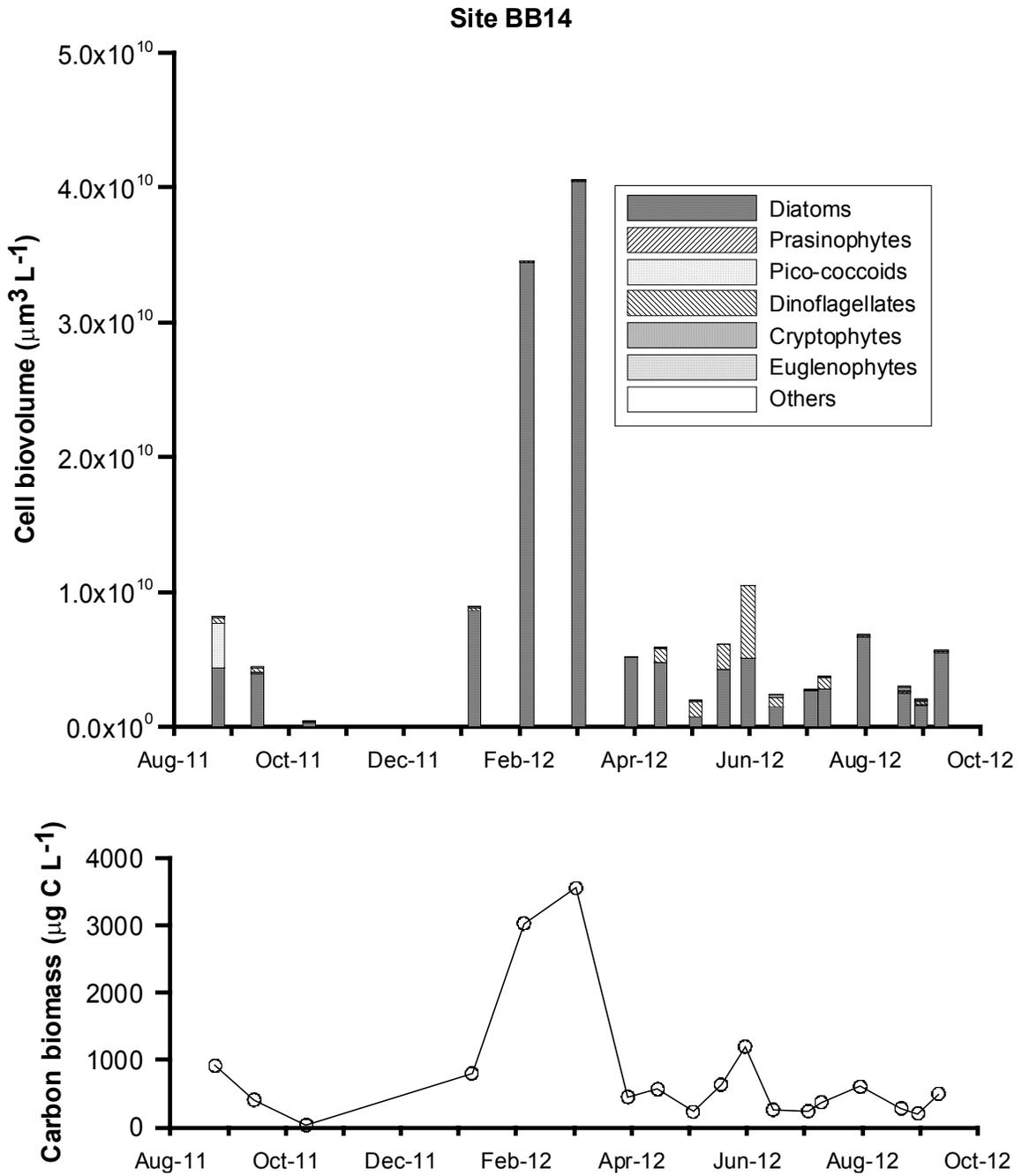


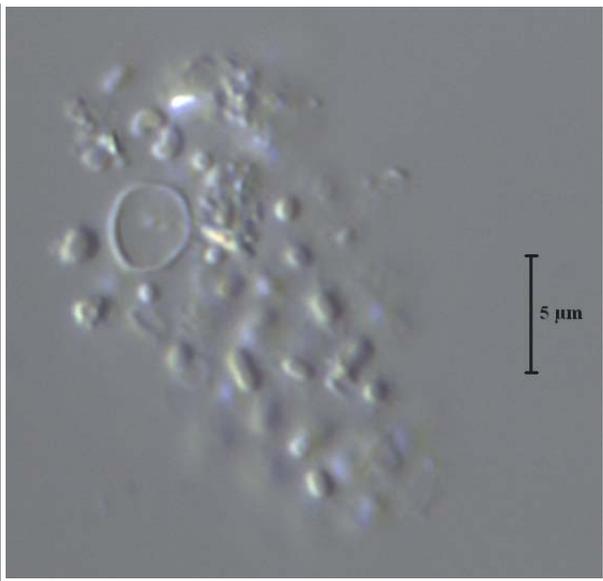
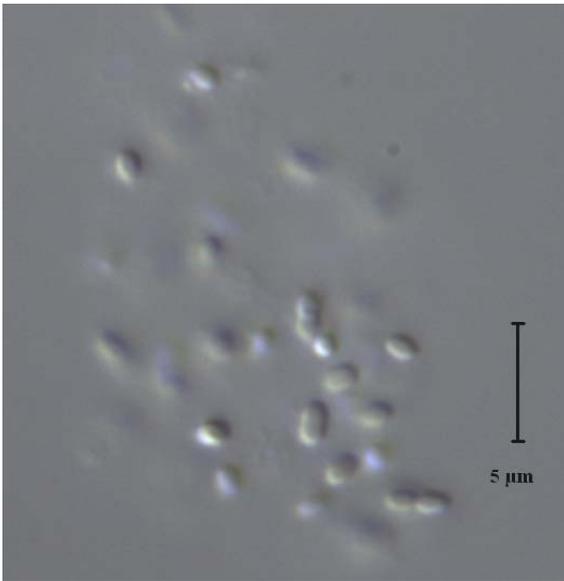
Fig. 21. Biovolume calculation and carbon biomass estimation of phytoplankton at site BB14 from August 2011 to September 2012.

APPENDICES

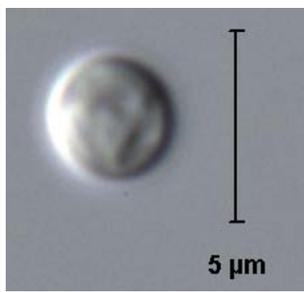
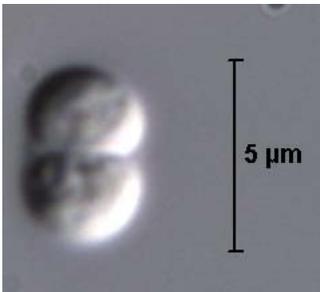
Appendix 1. Plate 1-20: Image documentation on major phytoplankton species.

Appendix 2 CD: Excel files with data on phytoplankton species cell density, biovolume calculation and carbon estimation for sites BB01, BB02, BB04, BB05, BB07, BB09, BB12 and BB14.

Plate 1: Pico-coccioids



Aphanocapsa sp.



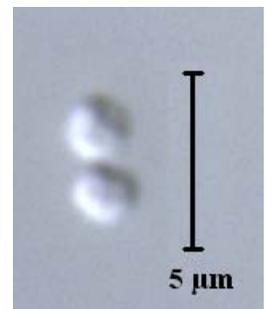
Nannochloris atomus ?



AA culture



Synechocystis salina ?



AA from sample



Unknown

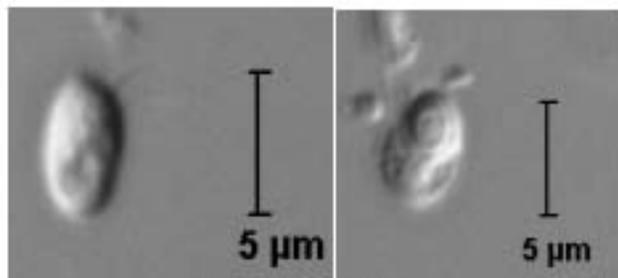
Plate 2: Cryptophytes



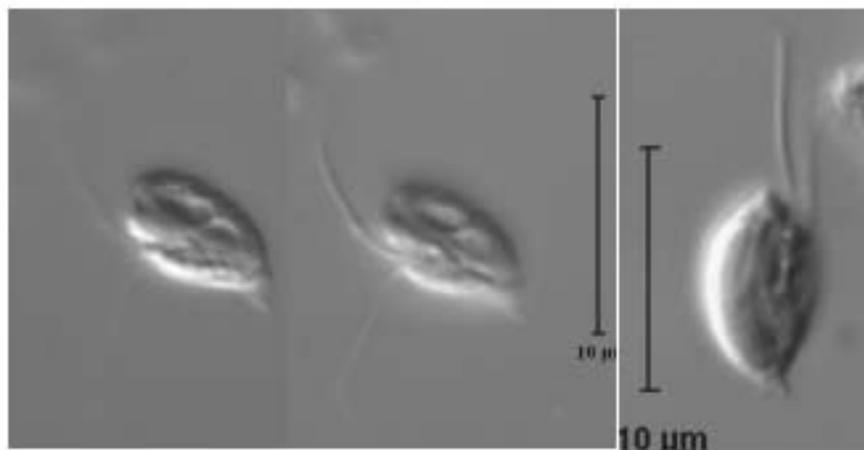
Hemiselmis virescens



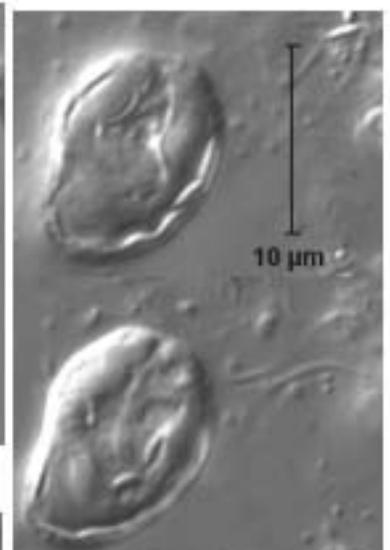
Hemiselmis sp.



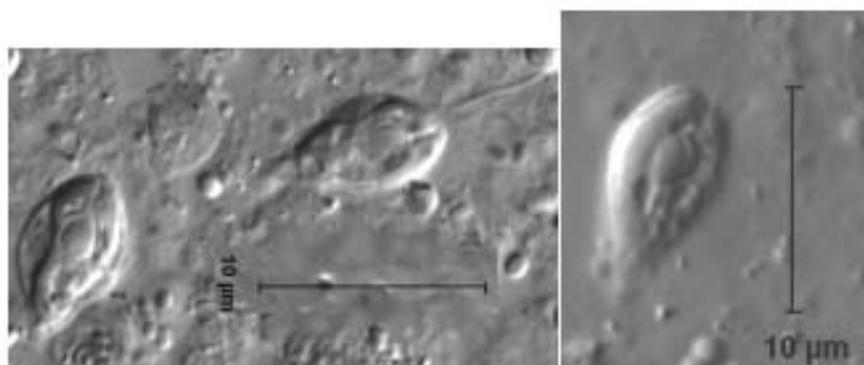
Hemiselmis sp.



Plagioselmis spp.

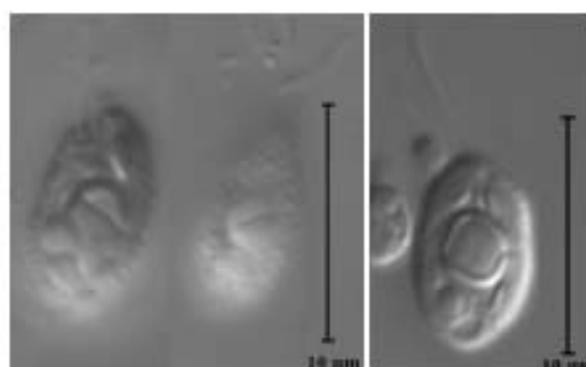
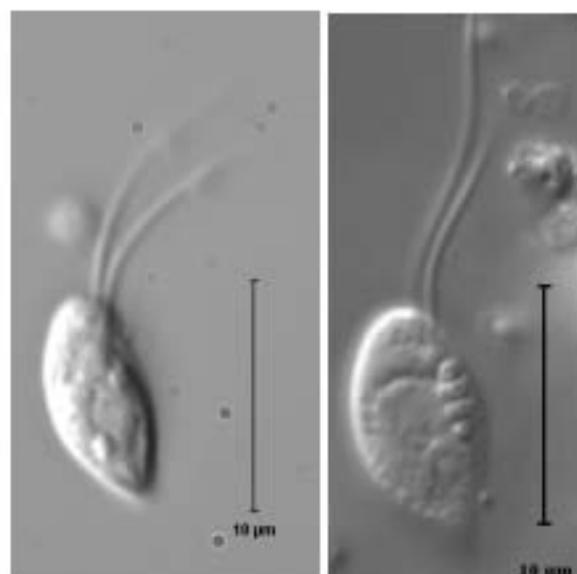


Rhodomonas sp.

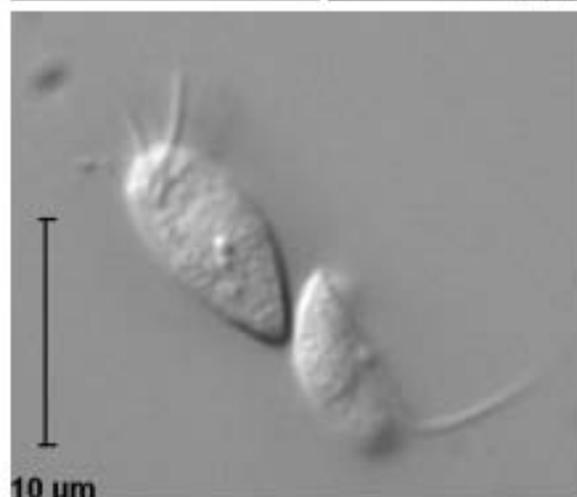


Teleaulax acuta

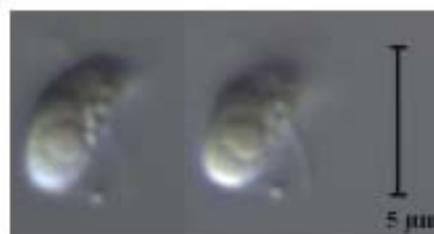
Plate 3: Cryptophytes (Cont.)



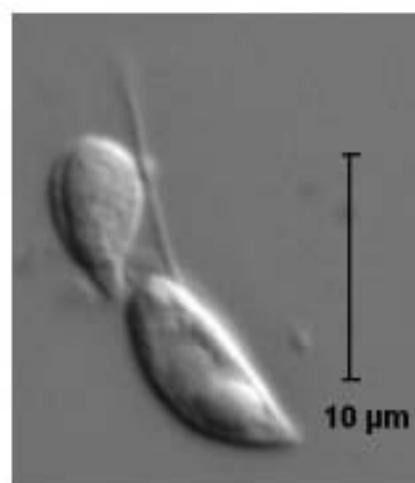
Rhodomonas salina



Leucocryptos marina



Hemiselmis virescens

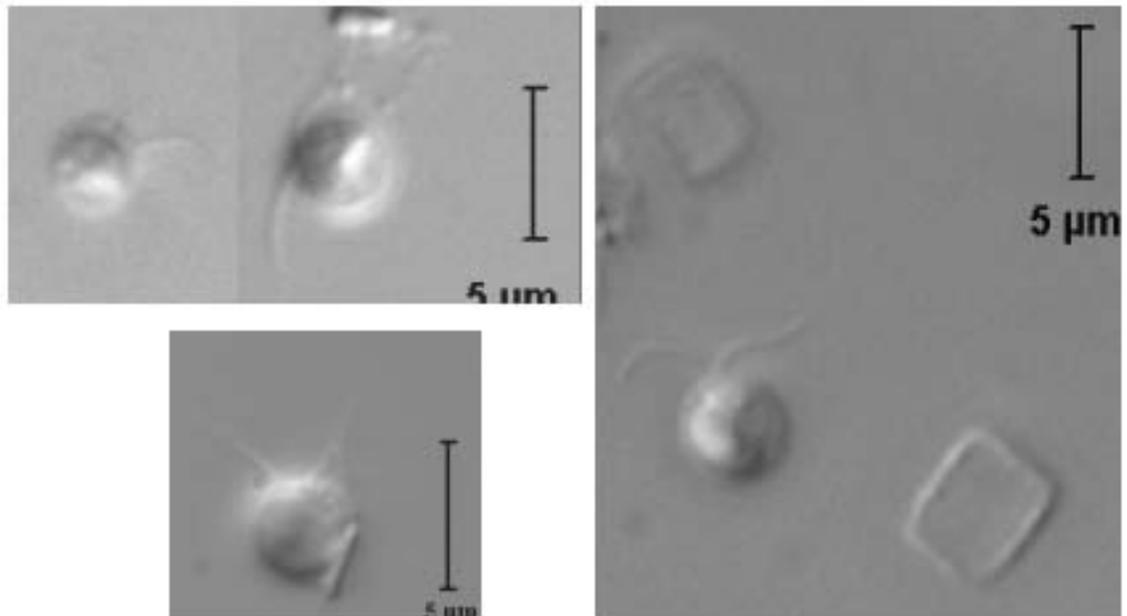


Plagioselmis sp. (smaller) & *Leucocryptos marina*

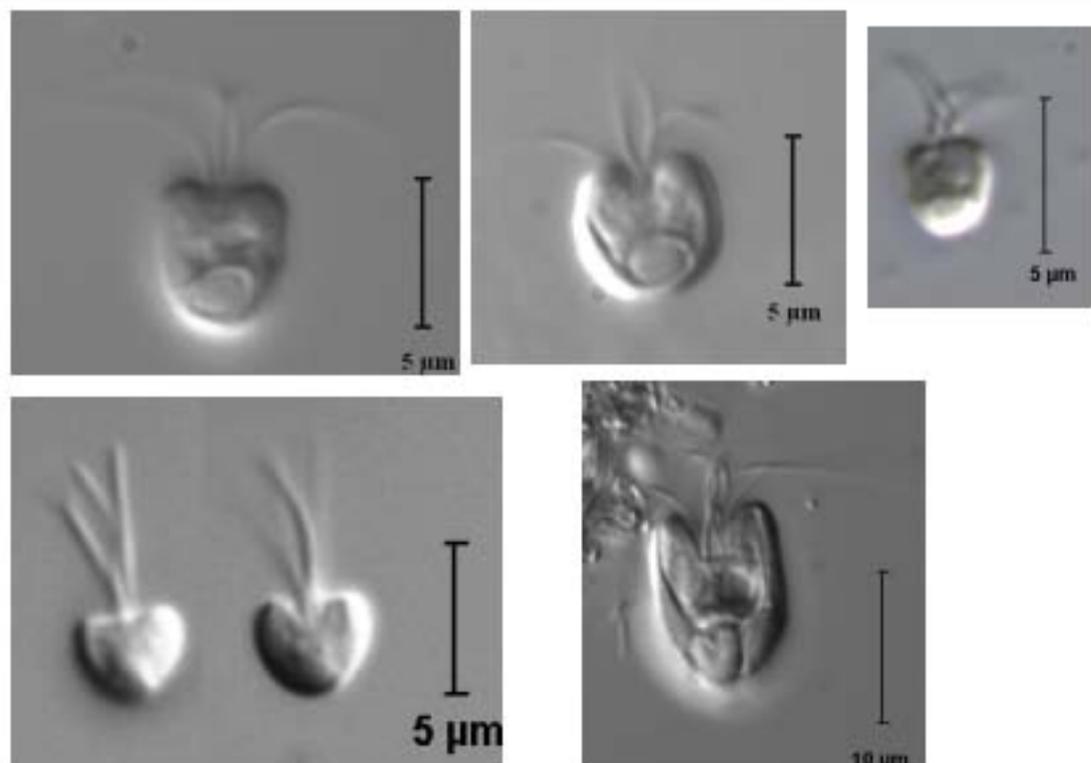


Plagioselmis sp.

Plate 4: Phytoflagellates

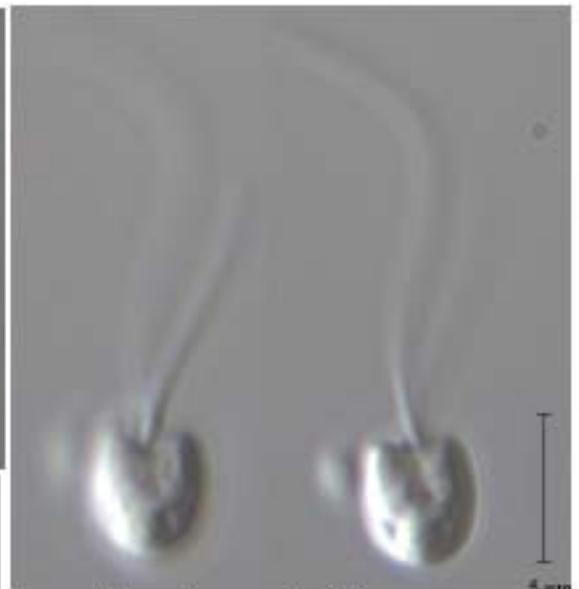
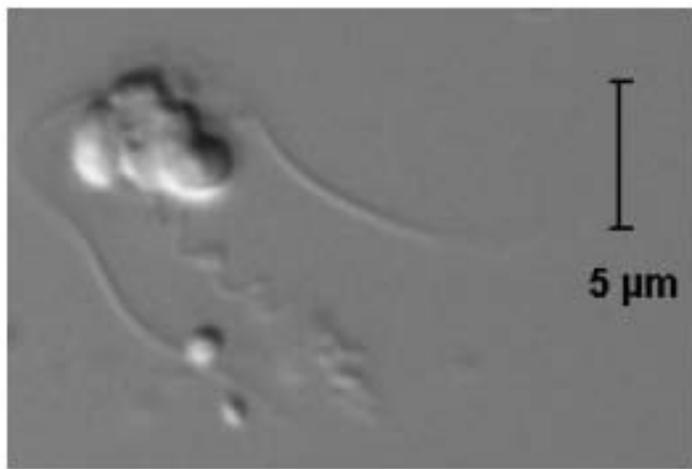


Chlamydomonas sp. 'c'

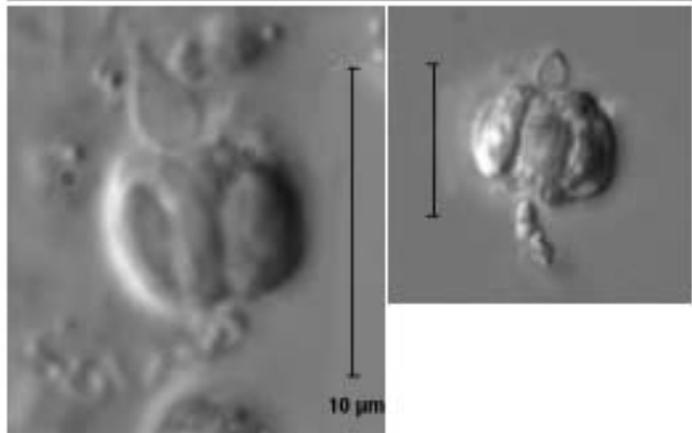


Pyramimonas spp.

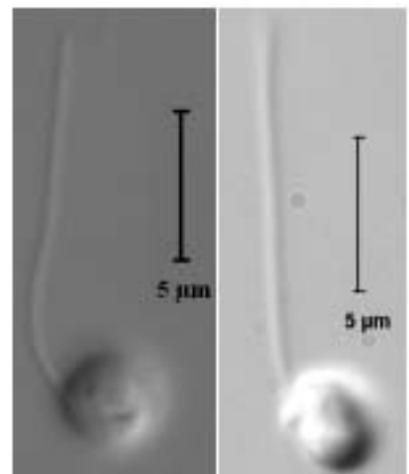
Plate 5: Phytoflagellates (Cont.)



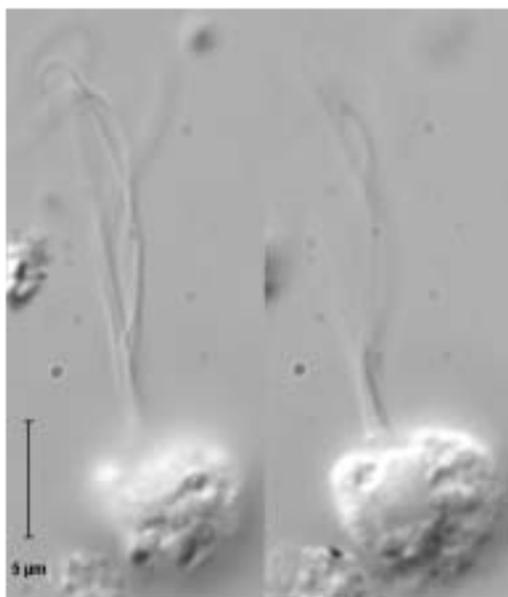
Pseudoscourfieldia marina



Pseudopedinella pyriformis



Resutor mikron



Pachysphaera marshalliae



Calycomonas ovalis

C. gracilis

Plate 6: Phytoflagellates (Cont.)



Dinobryon sp.



Eutreptiella sp.



Dictyocha fibula

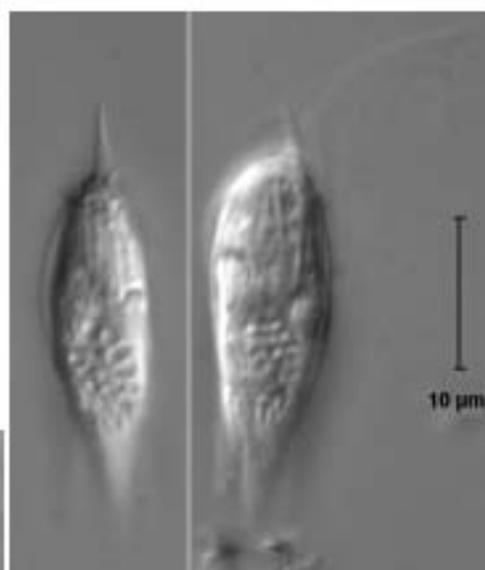


Heterosigma akashiwo

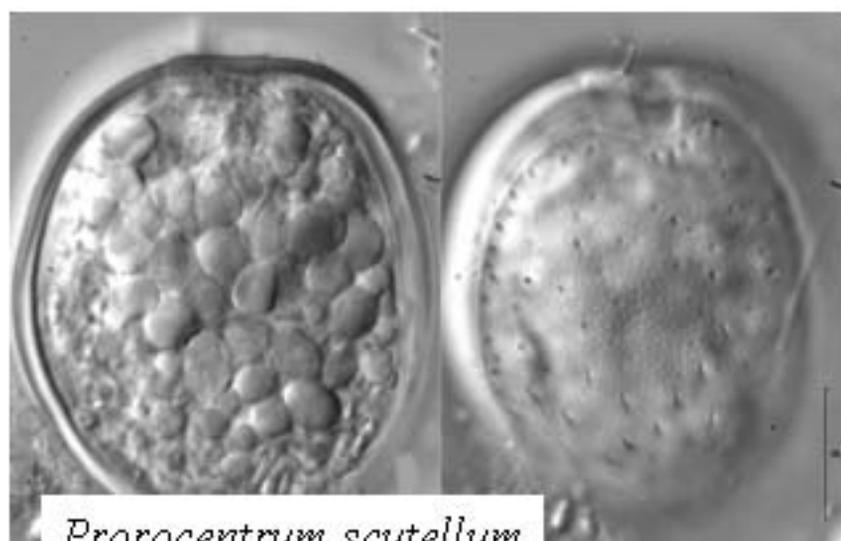
Plate 7: Dinoflagellates



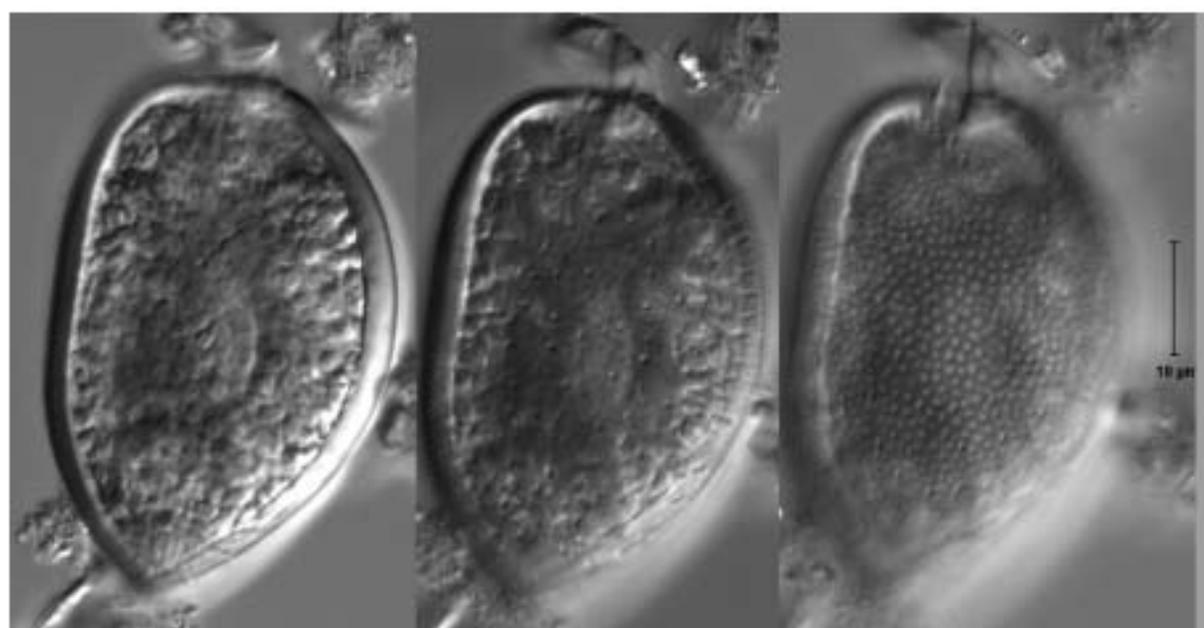
P. minimum



Prorocentrum triestinum

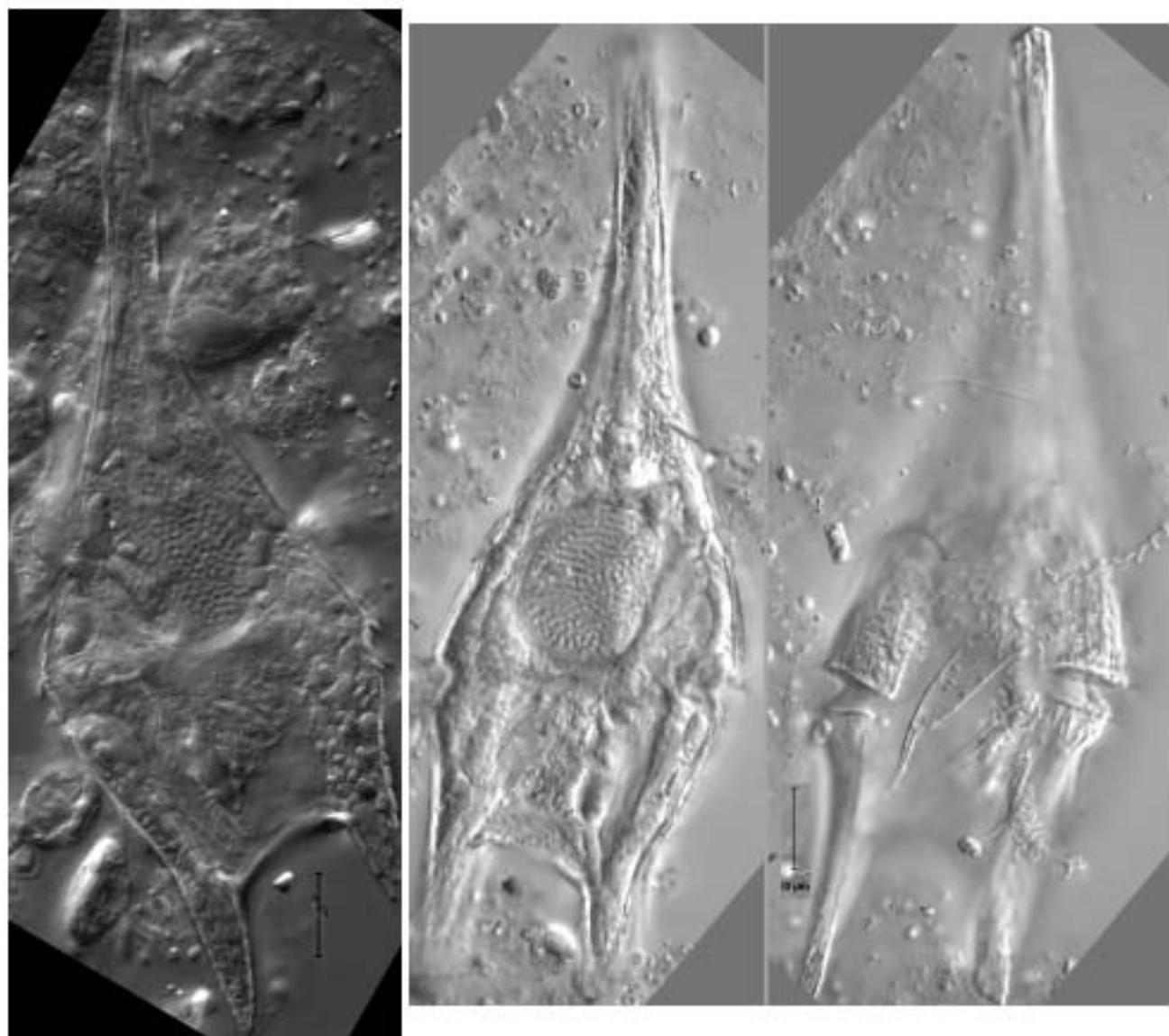


Prorocentrum scutellum



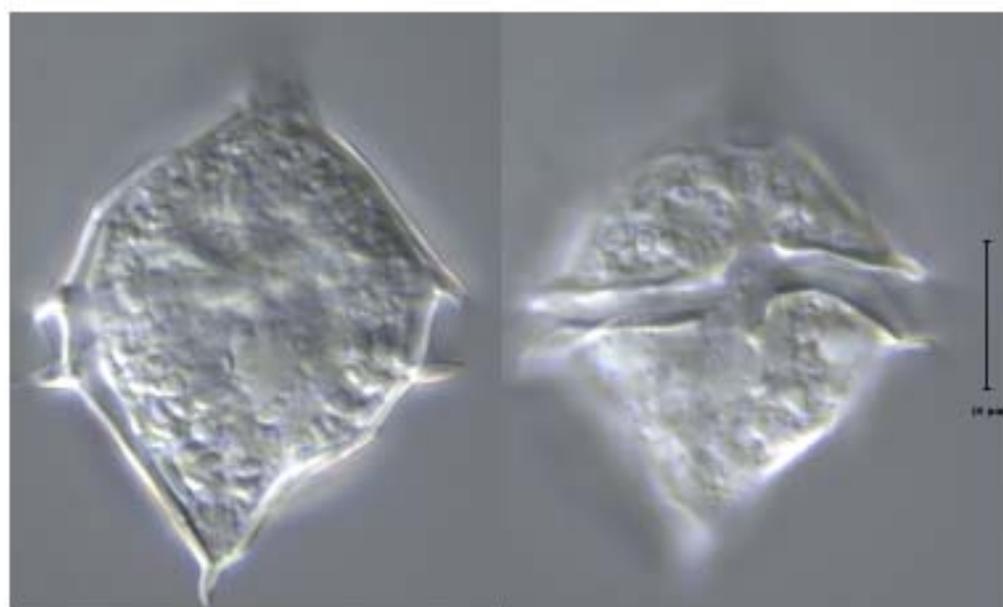
Prorocentrum micans

Plate 8: Dinoflagellates (Cont.)

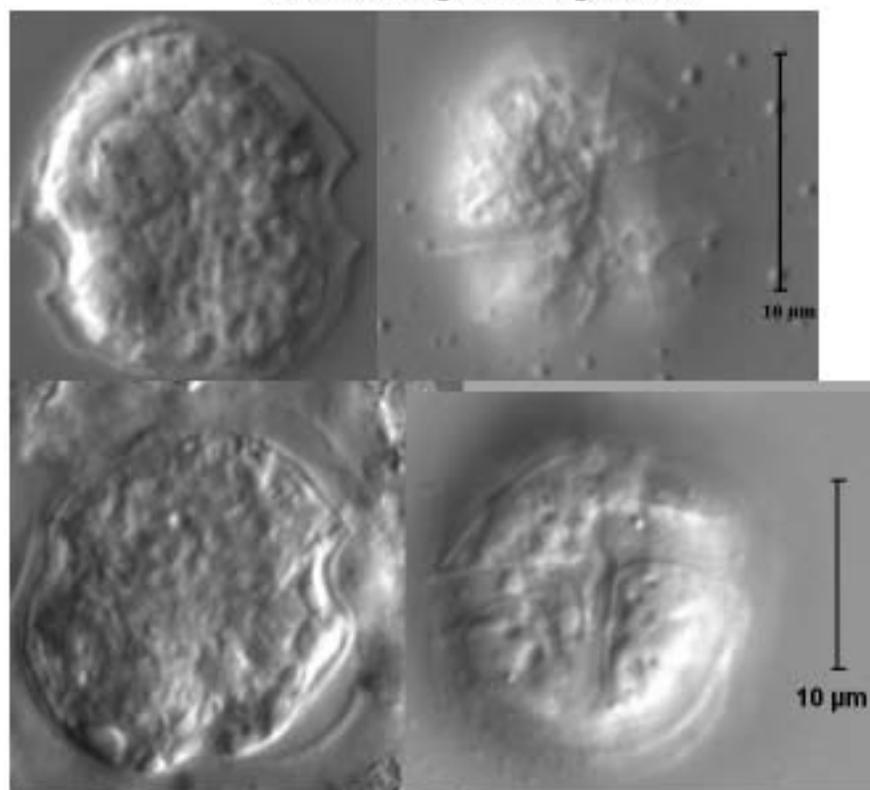


Ceratium lineatum

Plate 9: Dinoflagellates (Cont.)

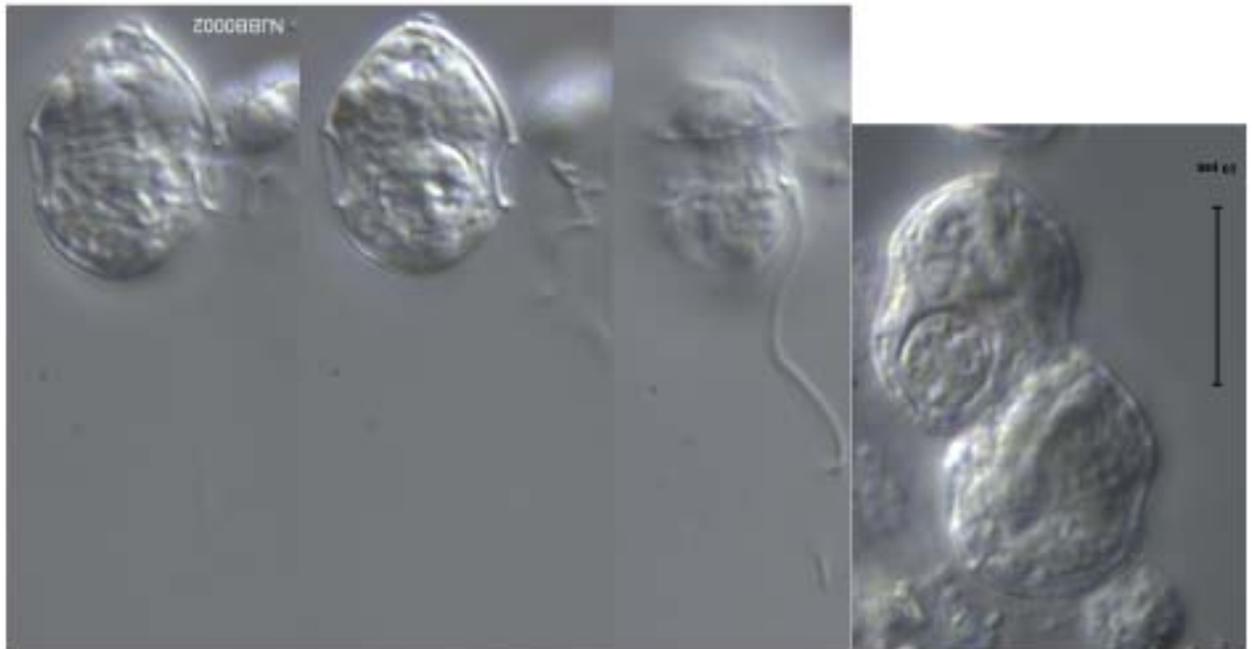


Heterocapsa triquetra

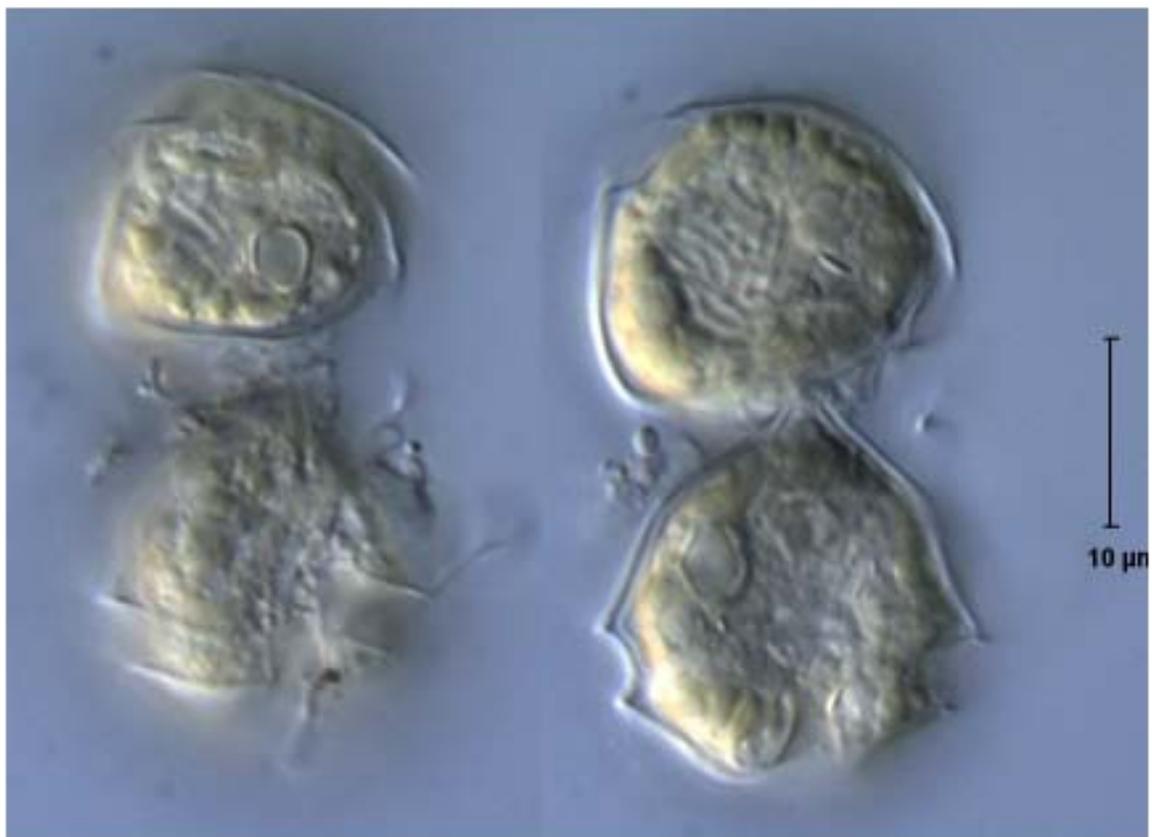


Gyrodinium estuariale

Plate 10: Dinoflagellates (Cont.)

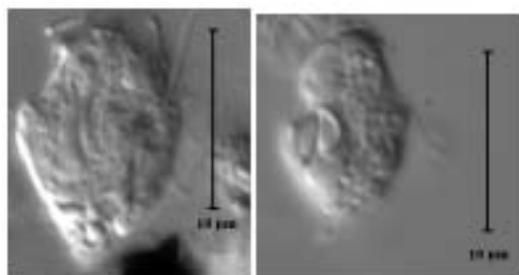


Gyrodinium flagellare

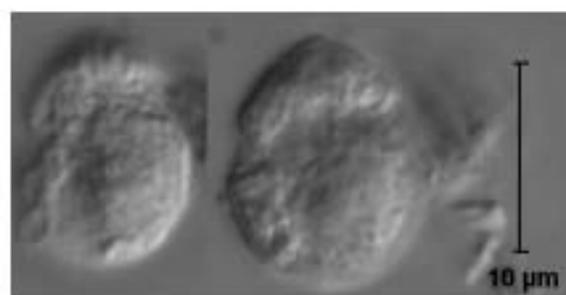


Scrippsiella trochooides

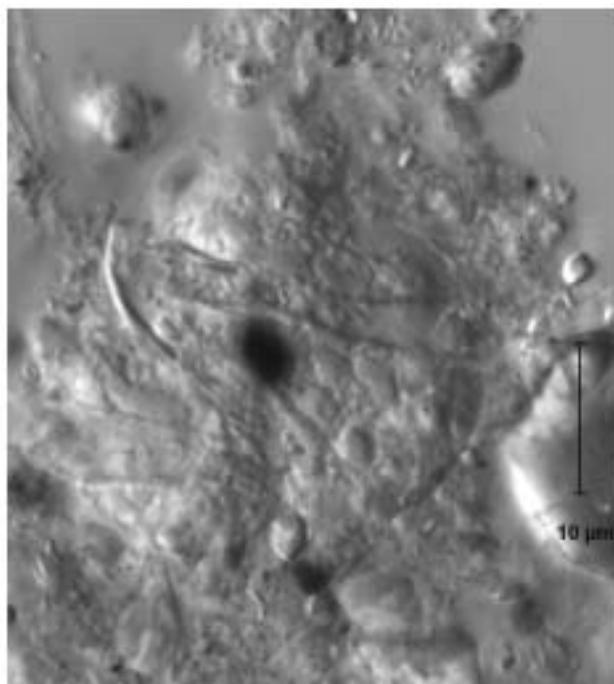
Plate 11: Dinoflagellates (Cont.)



Katodinium rotundatum



Gymnodinium sp.

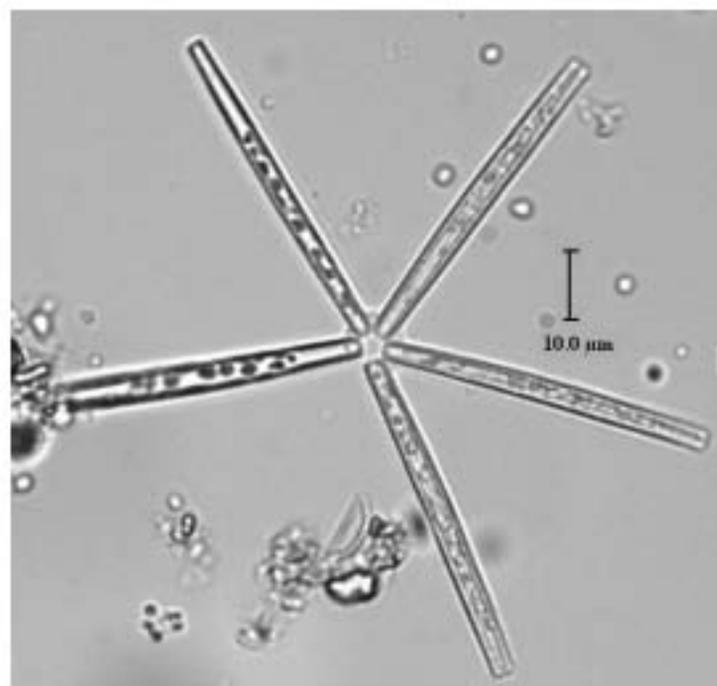


Cochlodinium sp.

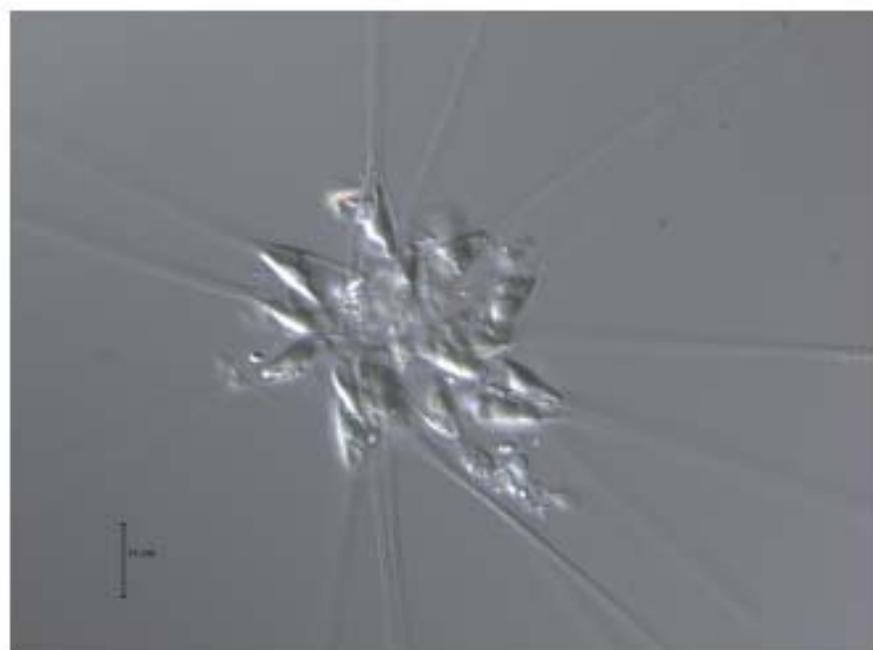


Gyrodinium spp.

Plate 12: Diatoms

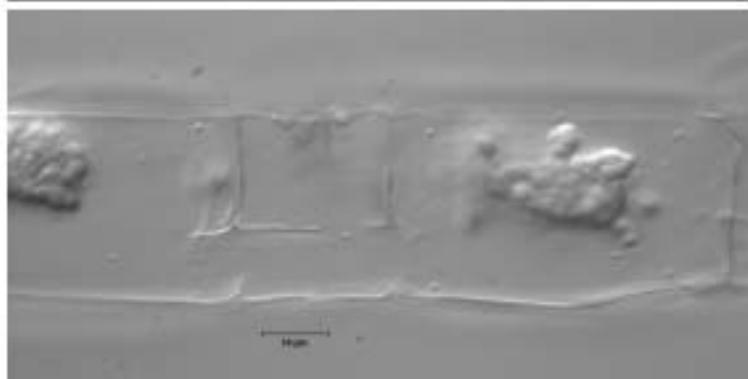
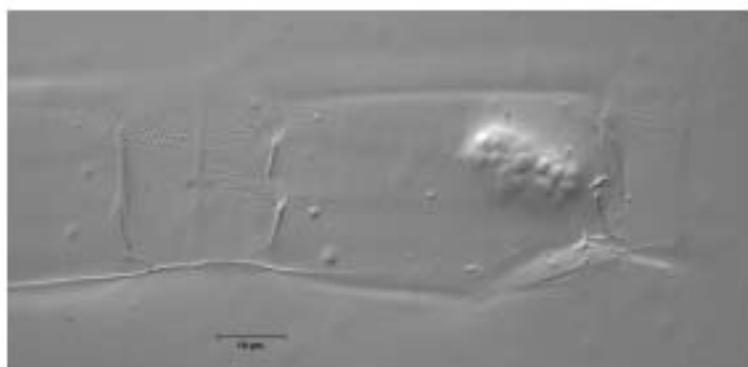


Thalassionema nitzschioides

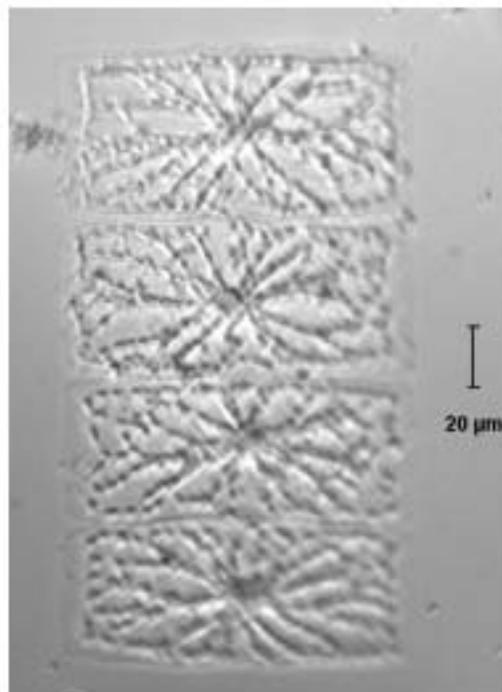


Asterionellopsis glacialis

Plate 13: Diatoms (Cont.)



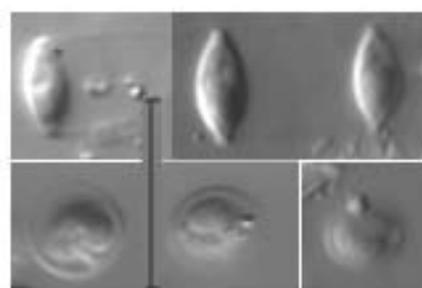
Lithodesmium undulatum



Helicotheca tamesis

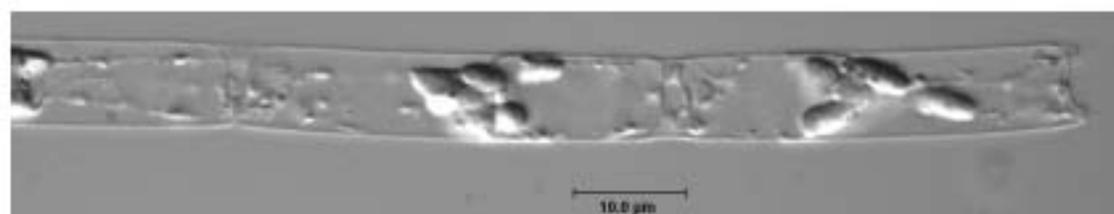


Skeletonema costatum

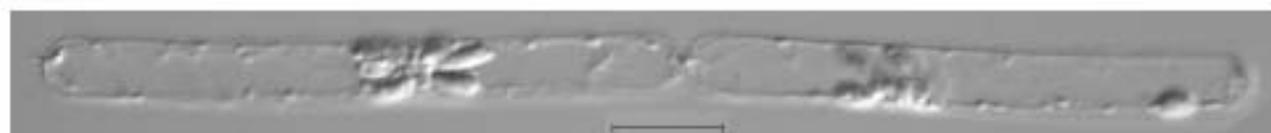


Skeletonema menzeli

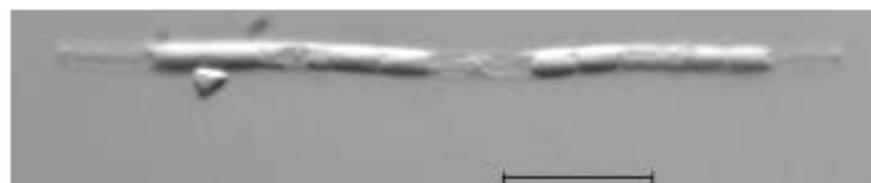
Plate 14: Diatoms (Cont.)



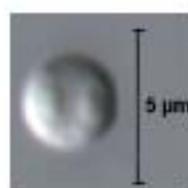
Cerataulina pelagica



Dactyliosolen fragilissimus



Leptocylindrus minimus

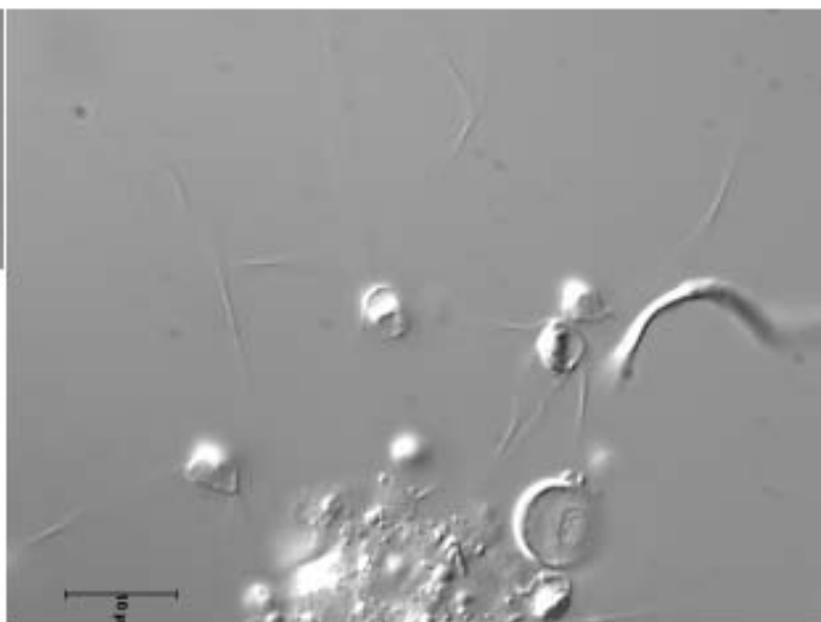
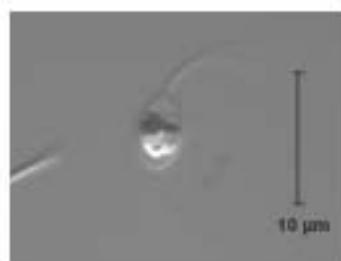
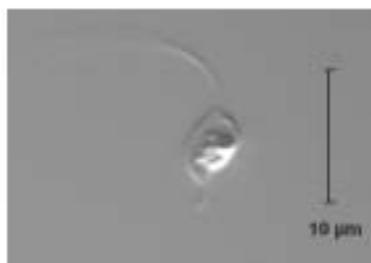
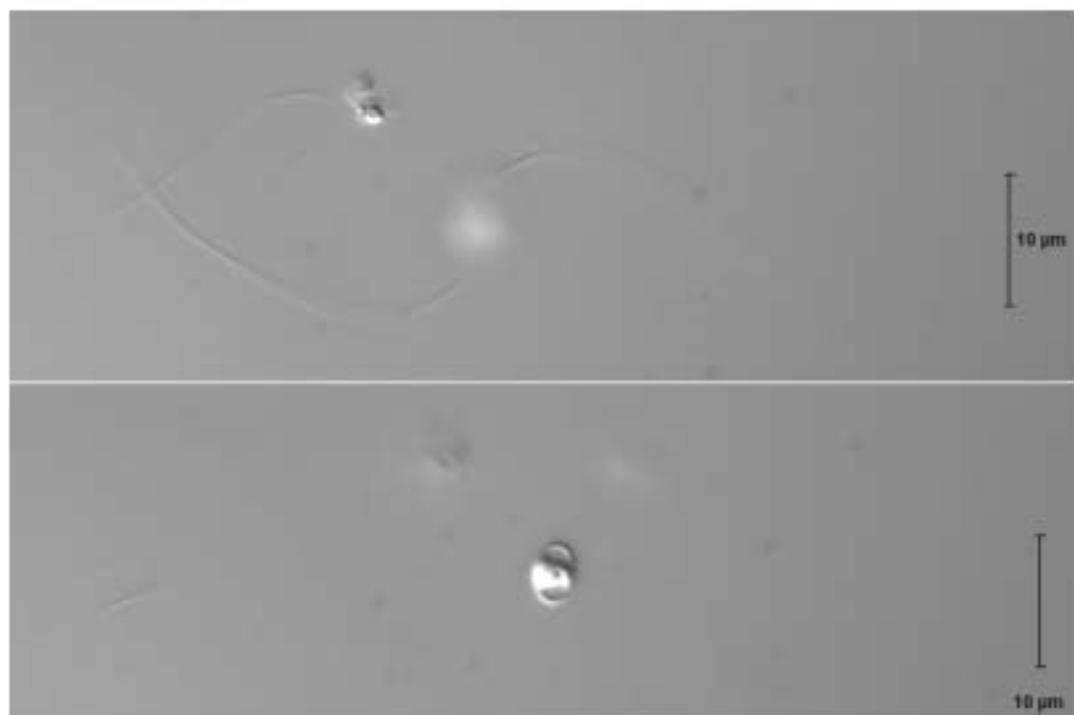


Cyclotella sp.



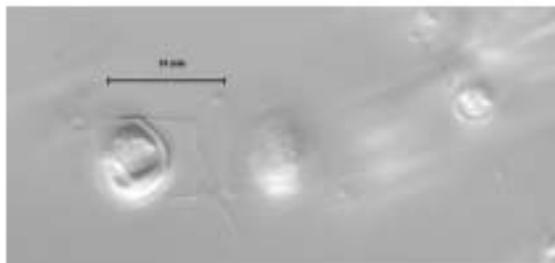
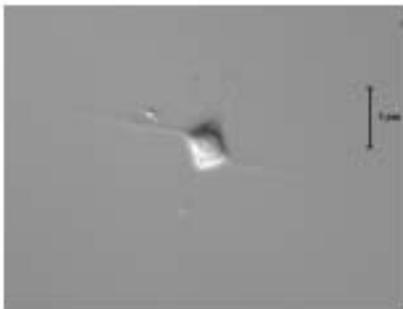
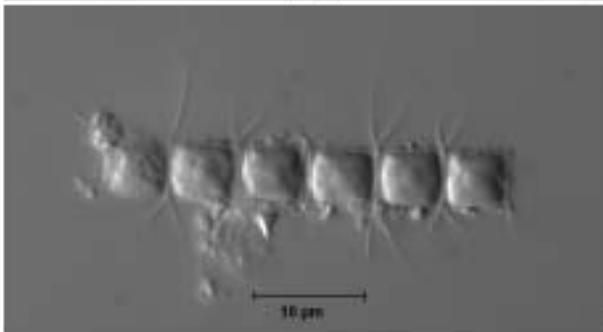
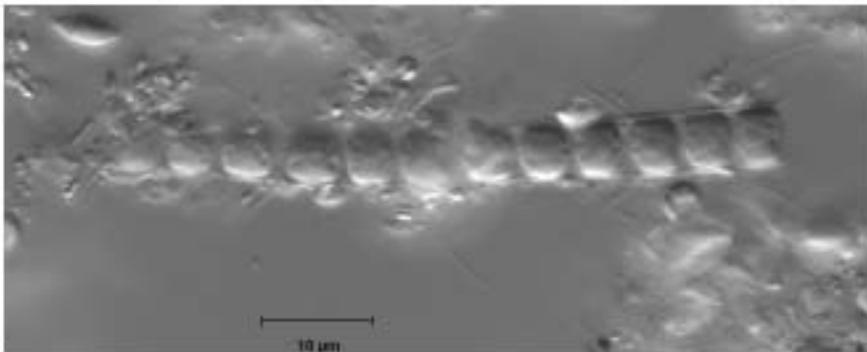
Thalassiosira proschkiniae

Plate 15: Diatoms (Cont.)



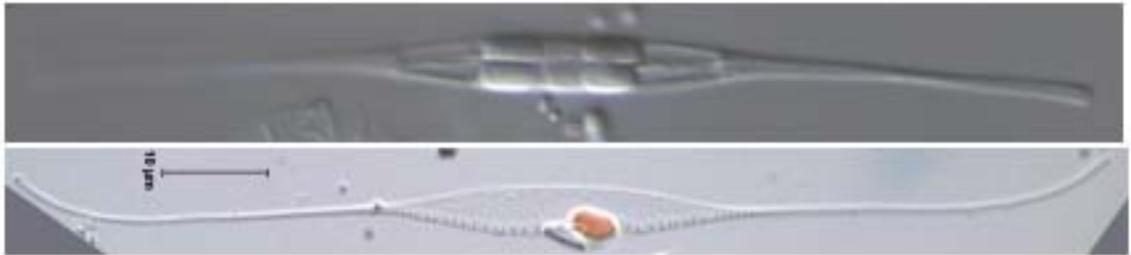
Chaetoceros cf. *tenuissimus*

Plate 16: Diatoms (Cont.)

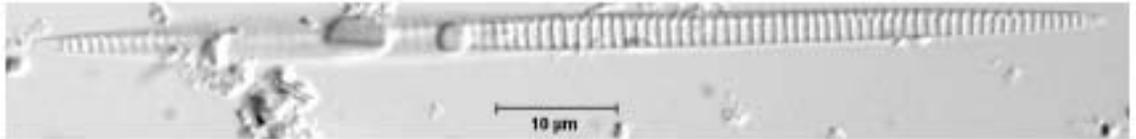


Chaetoceros spp.

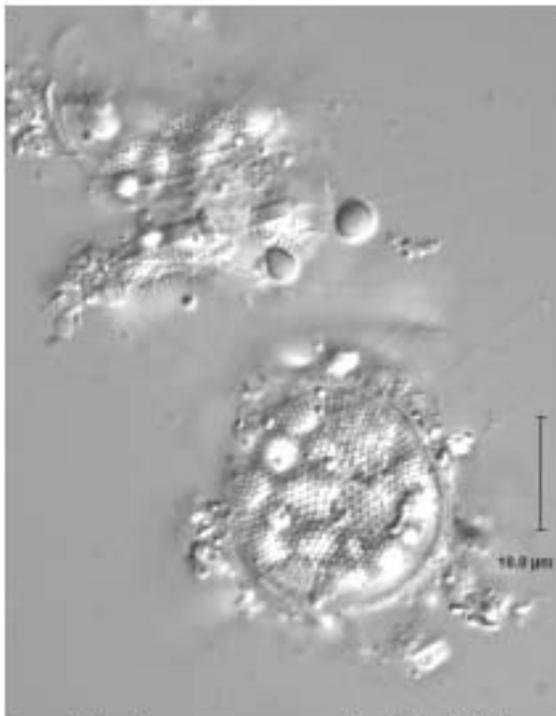
Plate 17: Diatoms (Cont.)



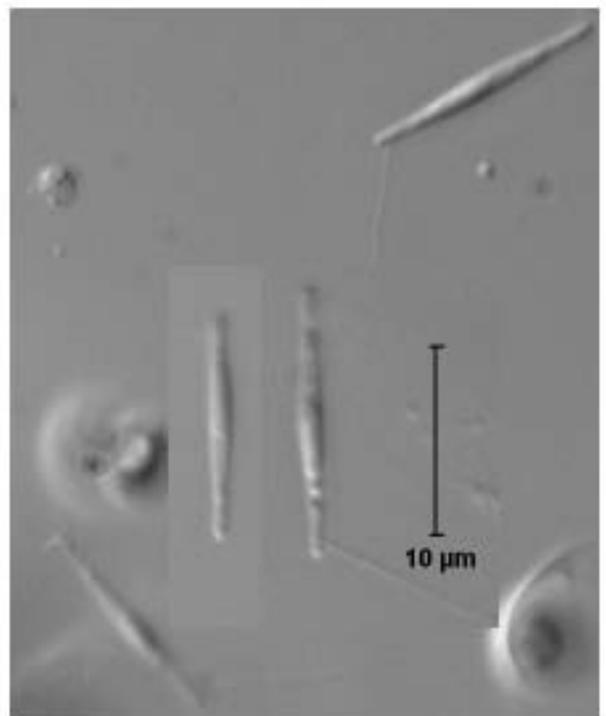
Cylindrotheca closterium or *Nitzschia longissima*



Pseudo-nitzschia sp.

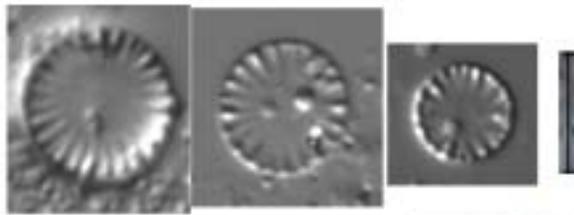


Thalassiosira nordenskiöldii

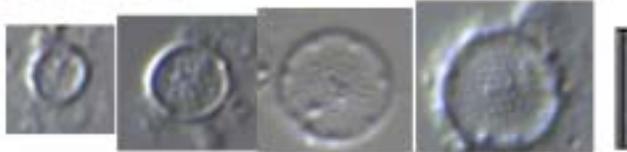


Phaeodactylum ? *tricorutum*

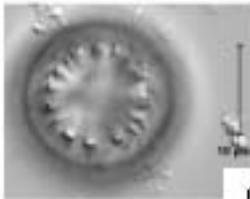
Plate 18: Diatoms (Cont.)



Cyclotella atomus



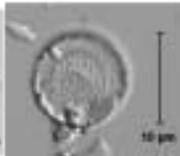
Thalassiosira proschkinæ



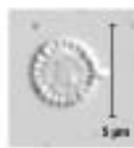
Paralia sulcata



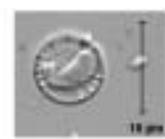
Cyclotella choctawhatcheeana



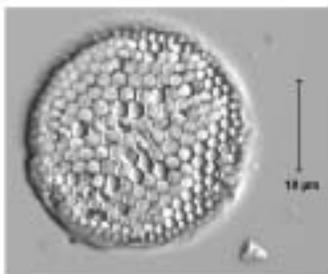
Cyclotella atomus



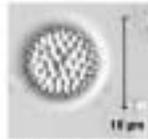
Cyclotella atomus



Cyclotella glabriuscula



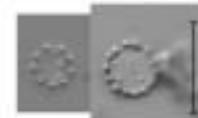
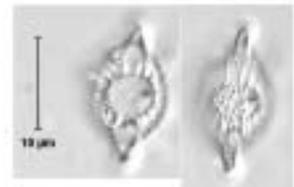
Thalassiosira eccentrica



Th. exigua

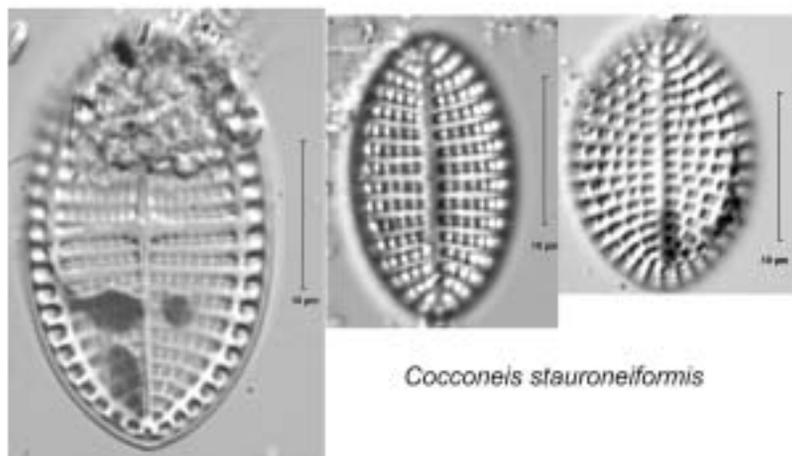


Hyalodiscus scoticus

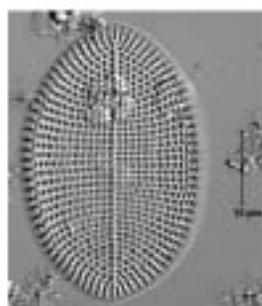


unknowns

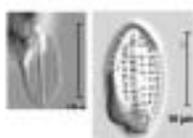
Plate 19: Diatoms (Cont.)



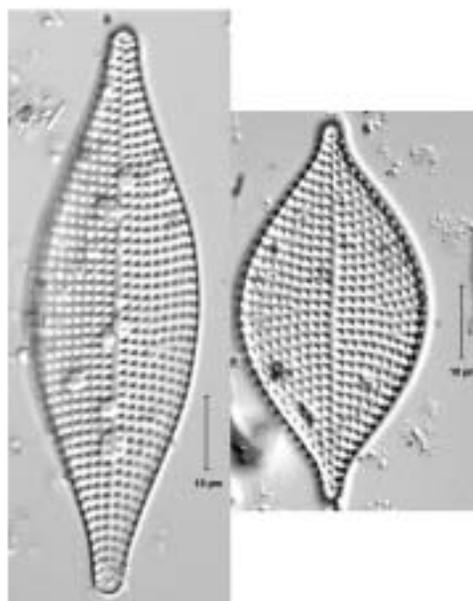
Cocconeis stauroneiformis



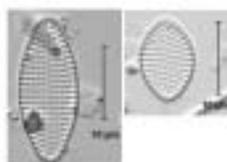
Cocconeis woodii



Cocconeis spp.



Raphoneis amphiceros



Delphineis minutissima

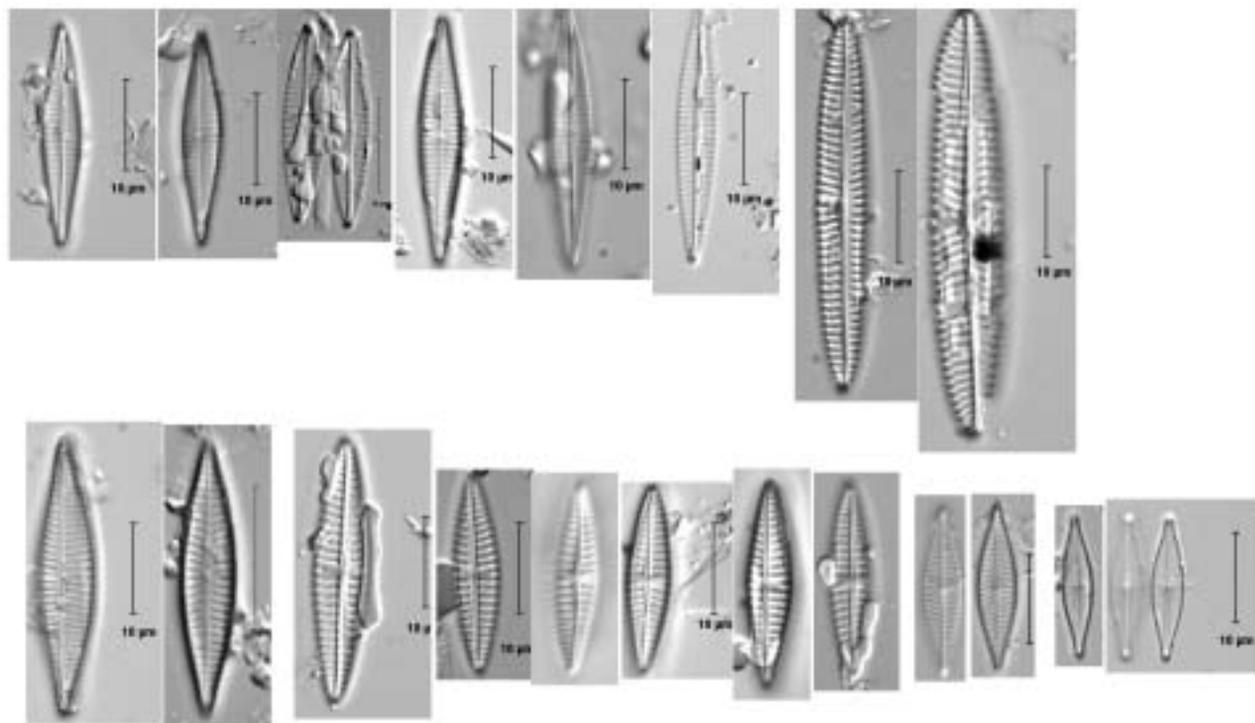


Grammatophora oceanica



Grammatophora angulosa

Plate 20: Diatoms (Cont.)



Navicula spp.