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AUTOTROPHIC PICOPLANKTON DISTRIBUTION AND ABUNDANCE IN THE CHESAPEAKE BAY, U.S.A.

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ABSTRACT : The autoprophic picoplankton consists of predominantly coccoid cyanobacteria that annually produce a single population peak in summer of 10^5-10^6 cells ml^{-1}. The base population remains at approximately 10^3 cells ml^{-1} during the other seasons. The summer maximum develops parallel to the rising water temperatures, then decreases gradually into fall. Mean sub-pycnocline concentrations remained well below those above the pycnocline between May and November, but were slightly higher during the colder months (December through April). Seasonal spatial differences and annual variations in abundance were noted.

Introduction

Picoplankton cells represent an ubiquitous component of marine and freshwater ecosystem (Johnson and Sieburth, 1979; Waterbury *et al.*, 1979; Stockner and Antia, 1986). They include heterotrophic and autotrophic cells in the water column that are between 0.2-2.0 μm in size (Sieburth *et al.*, 1978). These populations have been reviewed by Fogg (1986) and Stockner and Antia (1986), with further emphasis placed on the phototrophic picoplankton by Stockner (1988). Knowledge of food web relationships between these cells, the microzooplankton and other predators are considered necessary for an understanding of carbon production and utilization in various marine and freshwater habitats (Pomeroy, 1974; Stockner, 1988; Laval-Peuto *et al.*, 1986).

The Chesapeake Bay is the largest estuary in the United States, having an area of 6.5 x 10^3 km^2 and a mean depth of 8.4 m (Schubel and Pritchard, 1987). It is a partially mixed estuary having at times conditions that range from a stratification and pycnocline formation, to areas where vertical homogeneous conditions may occur. In general, there is a net surface flow out of the estuary, with sub-pycnocline waters having a net flow into the lower Bay.

The importance of the smaller phytoplankton components in the Chesapeake Bay was recognized by McCarthy *et al.* (1974), Van Valkenburg and Flemer (1974) and Marshall and Lacouture (1986). Ray *et al.* (1989) studied the autotrophic picoplankton over a 3 month period in a Chesapeake Bay tributary. They identified cells that were phycocyanin-rich and phycoerythrin-rich, which together made up 7% of the total autotrophic biomass (July through September). The phycocyanin-rich cells were most abundant, reaching counts of 10^5 cells ml^{-1}. Growth and productivity were measured for the autotrophic picoplankton in the Chesapeake Bay by Affronti and Marshall (1993, 1994) over a 15 month study. Their productivity ranged from 55.6% of the total productivity in July, to 2.3% in January. Cell concentrations also varied ranging from a summer peak of 9.2 x 10^8 cells l^{-1} to 7.2 x 10^6 cells l^{-1} in winter. These summer populations were dominated by phycocyanin-rich *Synechococcus* sp. Marshall and Nesius (1993) also reported major summer peaks of autotrophic picoplankton in 3 tributaries to the Chesapeake Bay. These rivers had summer maxima from 10^8 to 10^9 cells l^{-1}.

Methods

Monthly water collections were taken at 7 stations in the lower Chesapeake Bay from August

1989 througt December 1992 (Figure 1). Water was collected in carboys using a diaphragm pump, with a hose that was lowered to specific depths. At each station, a series of 3 *l* samples were taken at 5 equidistant depths between the pycnocline and surface and placed in a carboy for a composite sample. After mixing, replicate (2) 125 *ml* sub-samples were taken from the carboy and preserved immediately with glutaraldehyde (1% final concentration). This process was then repeated for waters below the pycnocline. In cases where the pycnocline was absent, composite samples were taken from waters in the upper third and lower third of the

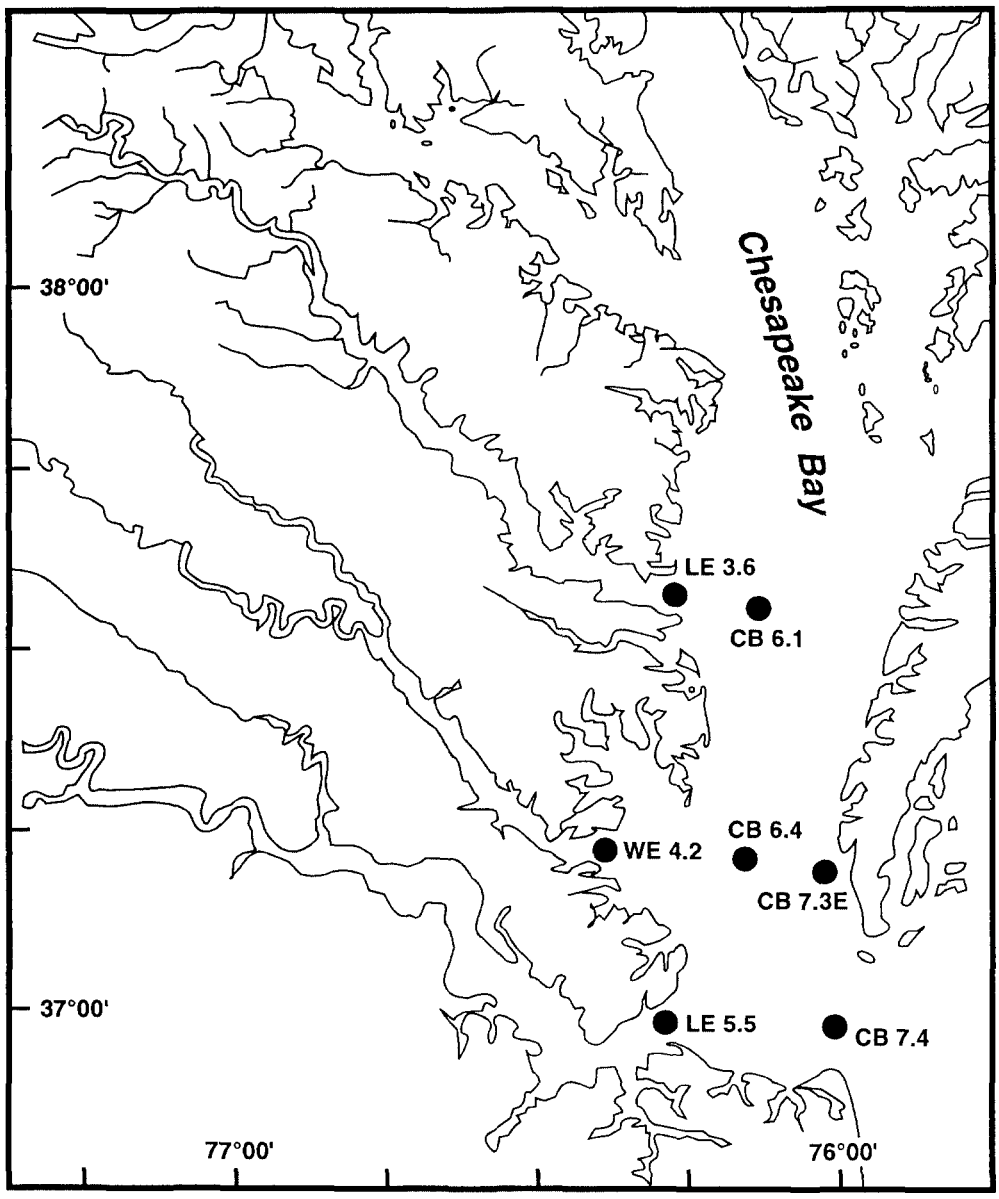

Figure 1. Station locations in the Chesapeake Bay.

water column. All samples were placed in an ice chest and returned to the laboratory for analysis, which was completed within 10 days.

For microscopic analysis, 1-2 *ml* (based on cell density) of the water sample was filtered on a 0.2 *μm* Nuclepore filter previously stained with Irgalan Black, backed with a separate 0.45 *μm* filter, at a vacuum pressure of 10 cm of Hg. Slide preparation followed, with the Nuclepore filter examined with a Zeiss Axioskop epifluorescence microscope equipped with a 100 watt mercury bulb. A green filter set was used (G546, FT580, LP590). The picoplankton that autofluoresced red or orange were counted as autotrophic cells (Davis and Sieburth, 1982). Twenty random fields and a minimum of 300 cells were counted at 1000x magnification, with an oil immersion objective (Neofluar 100x/1.30). Counts of the replicated samples were averaged for the representative concentrations.

Results

The ranges and mean values for the water quality parameters for the area are given in Table 1. The stations were located in mesohaline to polyhaline regions of the Bay, with salinity ranging from 11.6 to 33.4 ppt. Lowest mean values were associated with the western Bay stations farthest from the Bay entrance (CB6.1, LE3.6), with means for all stations between 16.8 and 26.6 ppt. Total nitrogen (TN) ranged from 0.12 (CB7.4) to 1.8 (LE5.5) $mg \cdot l^{-1}$. The highest values were along the western side of the Bay, plus station CB6.1, and at all stations in spring. Mean concentrations of total phosphorus (TP) ranged from 0.026 to 0.040 $mg \cdot l^{-1}$. The TN:TP ratios were lowest at the Bay entrance (10.0), with all stations averaging 15.4. In general, TN, TP, silicon, chlorophyll *a*, and total suspended solids (TSS) decreased west to east across the Bay. Secchi depths ranged from 1.4 to 2.5 m, being lowest along the western Bay.

The abundance patterns for the autotrophic picoplankton are given in Figures 2-8. Microscopic examination indicated the vast majority of the fluorescing cells were coccoid cyanobacteria. Each of the stations had a single summer pulse annual-

Table 1. Ranges of Water Quality Mesurements and Their Means for Stations in Chesapeake Bay, 1985-1992.

	CB6.1	CB6.4	CB7.3	CB7.4	LE3.6	WE4.2	LE5.5
TP	.02-.09	.01-.06	.01-.05	.01-.06	.02-.06	.02-.05	.01-.09
(mg/l)	.026	.028	.028	.029	.026	.03	.04
TN	.36-1.29	.17-.70	.14-.58	.12-.56	.20-1.29	.34-.93	.16-1.80
(mg/l)	.57	.39	.34	.29	.56	.51	.48
OXYGEN	5.7-13.6	6.7-13.4	6.2-14.4	6.6-12.1	6.1-14.1	5.6-14.0	6.3-13.6
(mg/l)	9.5	9.4	9.0	8.8	9.3	8.6	9.3
TSS	5.0-31.7	4.0-52.0	4.0-60.0	4.0-86.0	5.0-37.5	5.0-48.4	4.0-160.5
(mg/l)	11.5	7.7	7.8	8.0	11.8	15.5	11.2
CHLOR-a	3.2-44.3	1.1-46.0	1.1-34.7	.2-28.7	3.2-79.8	3.2-25.0	.37-61.2
(μg/l)	9.5	8.8	6.7	5.01	10.0	8.2	11.11
SALINITY	12.3-23.9	14.6-25.5	16.7-27.5	18.0-33.4	12.1-21.3	13.2-24.0	11.6-25.4
(ppt)	17.6	20.4	23.0	26.6	16.8	20.1	20.1
SILICON	.05-1.5	.02-.88	.02-.60	.02-.64	.05-1.42	.05-1.3	.02-1.52
(mg/l)	.26	.22	.17	.15	.34	.47	.55
SECCHI	0.7-3.5	.9-3.5	1.0-4.3	.7-5.8	.9-4.0	.6-3.2	.7-3.1
(m)	2.0	1.9	2.1	2.5	1.8	1.6	1.4
N:P	21.9	13.9	12.1	10.0	21.5	17.0	12.0

ly. Prior to this development the base concentrations were approximately 10^3 cells ml^{-1}. The summer peaks reached 10^6 cells ml^{-1} in 1989, 1990 and 1991, with the highest concentrations noted (CB6.1) in August 1991 at 2.97 x 10^6 cells ml^{-1} above the pycnocline, and 1.98 x 10^6 cells ml^{-1} in July 1990 below the pycnocline (LE3.6). Station LE3.6 was atypical in having the summer picoplankton maxima of 1990 and 1991 greater below the pycnocline. At each station, the seasonal abundance pattern throughout the water column had lowest mean concentrations in winter. Maximum summer abundance differed among the stations each year, with highest concentrations occurring in the central Bay stations CB6.1 and CB6.4, and LE3.6 and WE4.2 located along the western side of the Bay. Lowest concentrations occurred at the Bay entrance (CB7.4) where nutrient levels were lowest and salinity highest. In addition to these differences among stations, the 1992 summer peak at all stations was the lowest of the study. The summer maxima in 1992 were at 10^5 cells ml^{-1}. During each year of the study, summer development of the autotrophic picoplankton paralleled the rise and decrease of water temperatures (Figures 2-8). There were approximately a 3-4 month station lag in the relation between rising temperatures and the summer picoplankton pulse, with peak picoplankton development occurring at temperatures above 22℃. Although these patterns were closely linked to temperature changes in the water column, a variety of water quality variables would be expected to also influence the development of these cells (e.g. light, nutrients, predation, residency time, etc.) and are not addressed here (Waterbury *et al.*, 1986). The data sets have been combined to present the mean concentrations and the seasonal development patterns for the Chesapeake Bay over the 41 month study (Figure 9).

The mean monthly abundance values for all station are presented in Table 2. Summer picoplankton concentrations are charcteristically higher above the pycnocline in comparison to levels below the pycnocline. This pattern is typical during the period of major development (May-November), but below pycnocline levels were greater during the colder months (December-April) when surface growth rates were markedly reduced. Lowest cell concentrations occurred in January below the pycnocline, and in February above the pycnocline. The mean monthly concentrations indicate the picoplankton are at a fairly constant level of abundance from mid-winter (January) to mid-spring (April). During May concentrations rise sharply, then increase rapidly in summer to peak abundance levels in July and August. The decline in abundance is more gradual into fall, before reaching the seasonal lows of winter. Above the pycnocline, cell concentration maxima occurred in June, July and August, with mean values for these months 6.22, 8.88, and 9.07 x 10^5 cells ml^{-1} respectively (Table 2). The lowest concentrations were in February at 9.6 x 10^3 cells ml^{-1}. Below the pycnocline, June through August were also the periods of greatest abundance, with concentrations between 4.19-4.42 x 10^5 cells ml^{-1}. Lowest numbers occurred in January at 10.7 x 10^3 cells ml^{-1}.

Discussion and Conclusions

The concentrations of the autotrophic picoplankton in the Chesapeake Bay followed a

Table 2. Monthly mean cell concentrations (times 10^3 ml^{-1}) from all Chesapeake Bay stations for autotrophic picoplankton, above(Abv) and below (Blw) the pycnocline, from August 1989 to December 1992.

	J	F	M	A	M	J	J	A	S	O	N	D
Avb	10.5	9.6	12.2	10.8	76.8	622.8	880.6	907.0	333.2	109.7	54.0	38.3
Blw	10.7	14.1	17.1	18.3	66.0	419.9	442.4	426.9	168.5	86.6	37.7	42.4

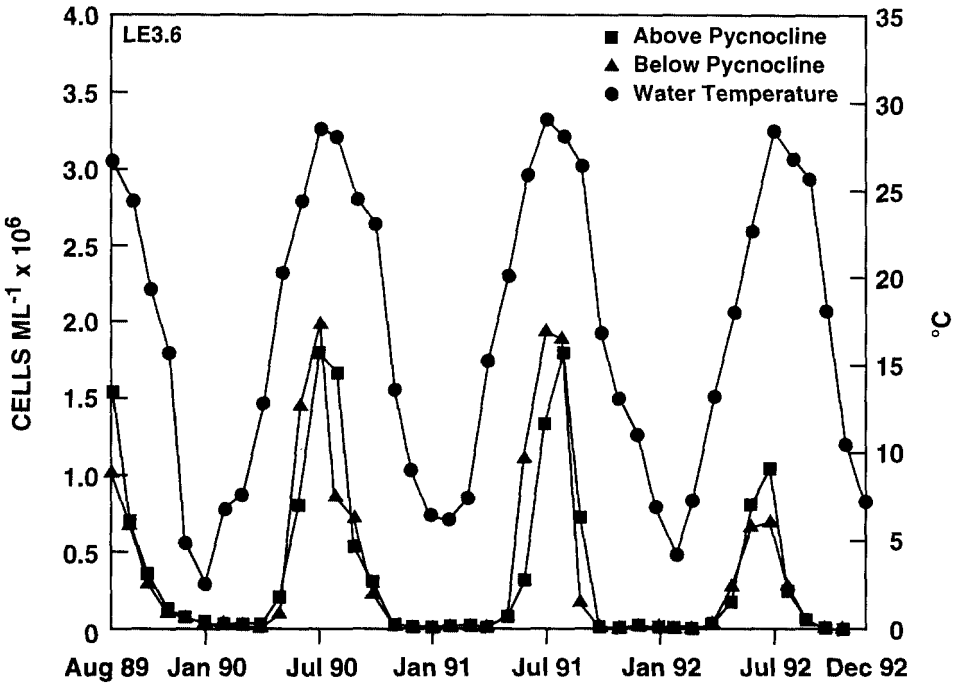

Figure 2. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water temperatures at Station LE3.6.

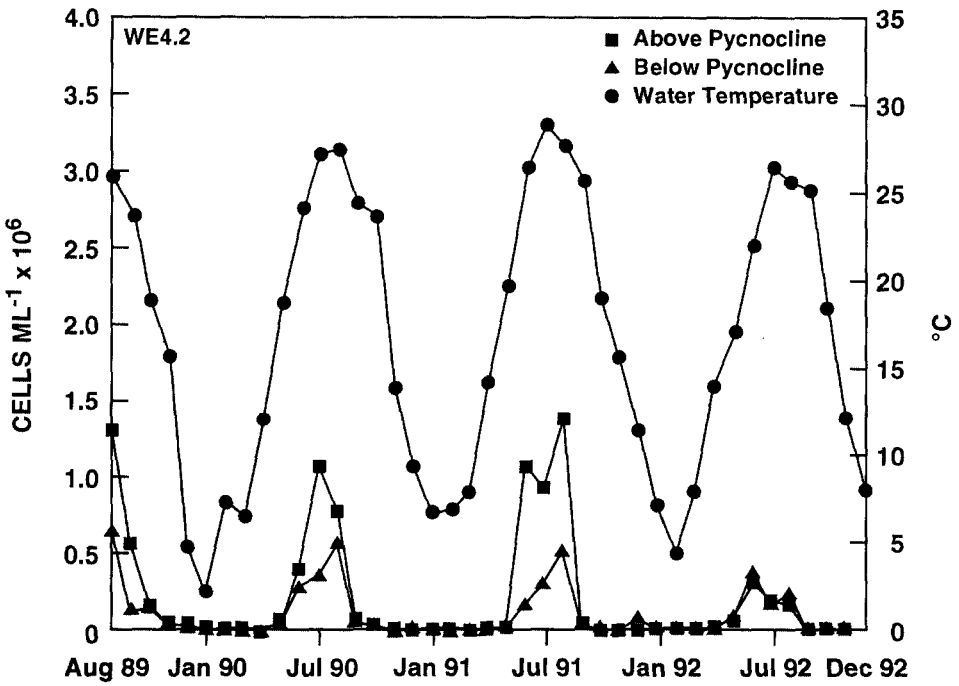

Figure 3. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water temperatures at Station WE4.2.

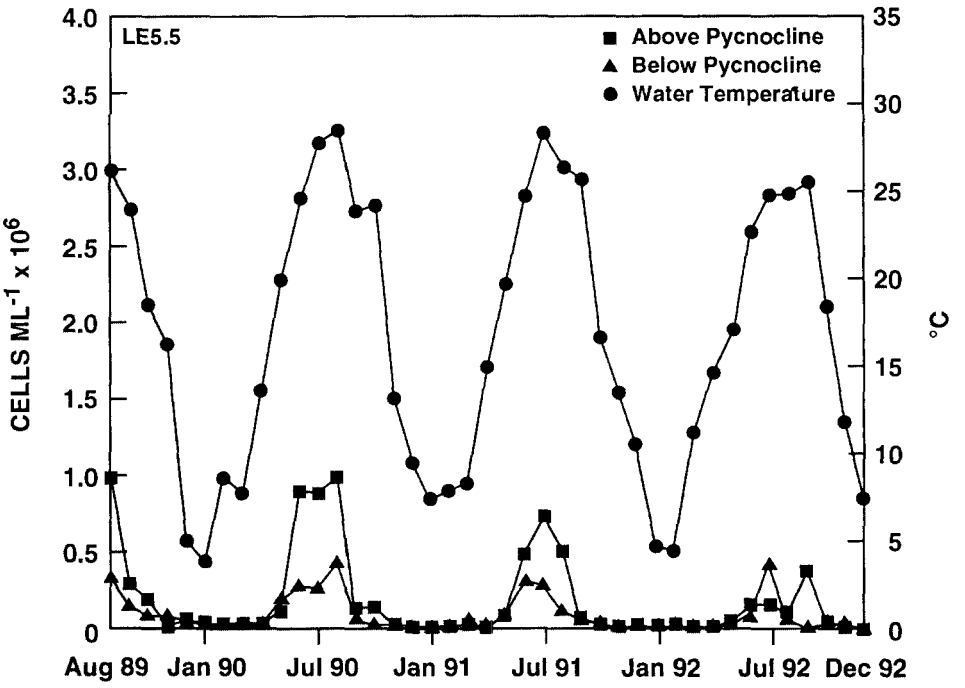

Figure 4. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water tempera tures at Station LE5.5.

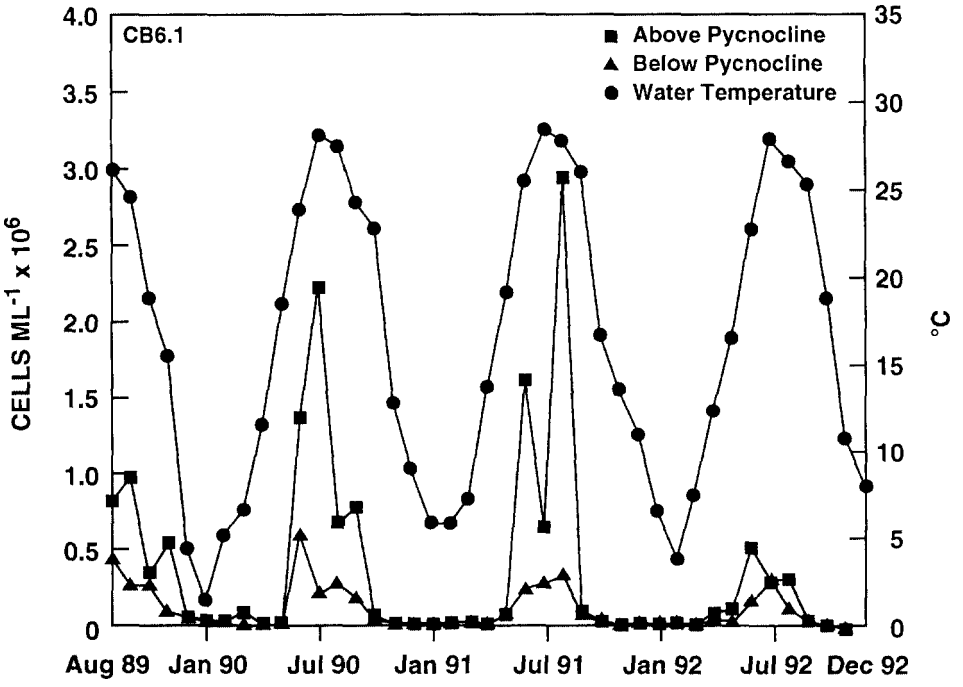

Figure 5. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water tempera tures at Station CB6.1.

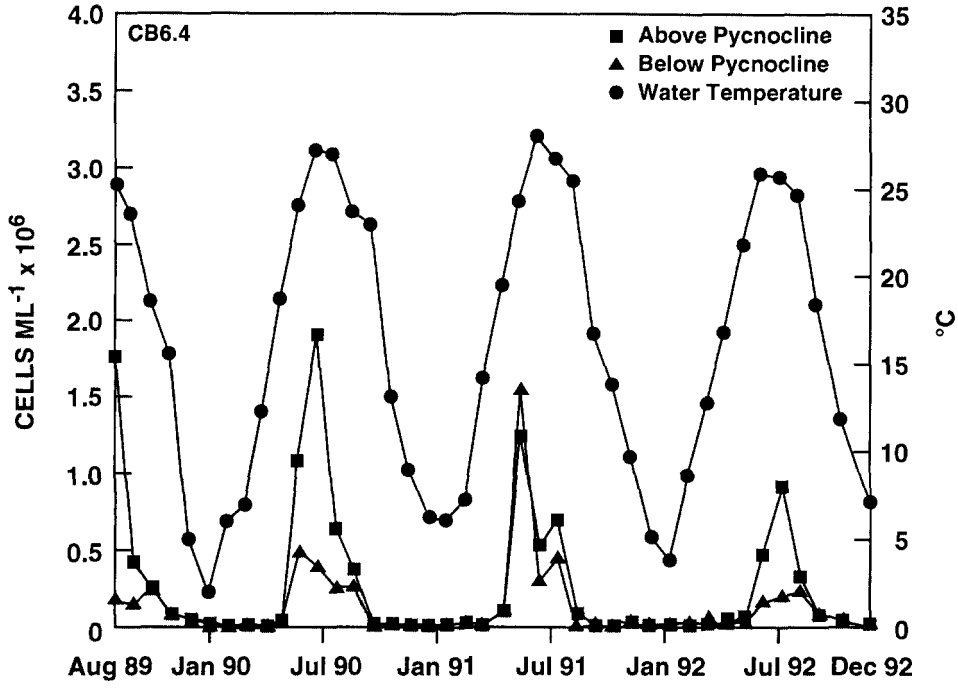

Figure 6. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water temperatures at Station CB6.4.

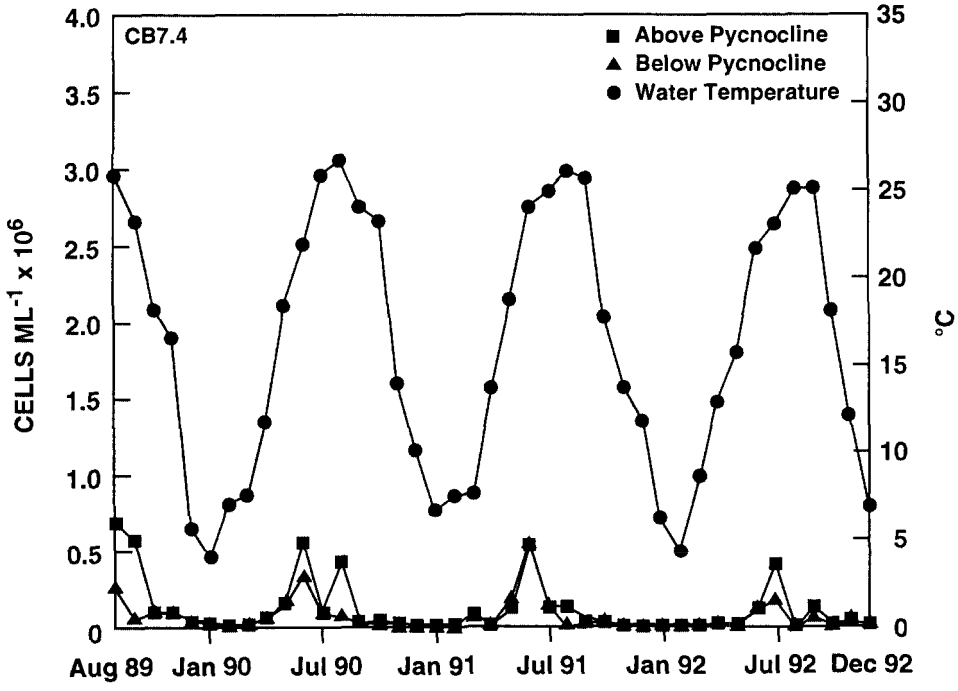

Figure 7. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water temperatures at Station CB7.4.

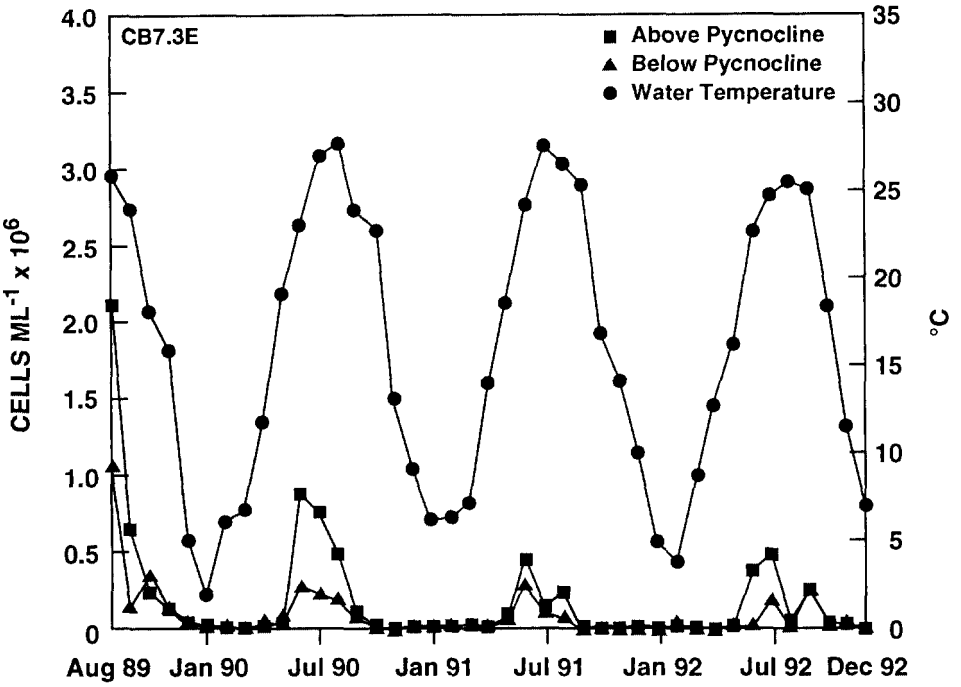

Figure 8. Autotrophic picoplankton concentrations above and below the pycnocline, with surface water temperatures at Station CB7.3E.

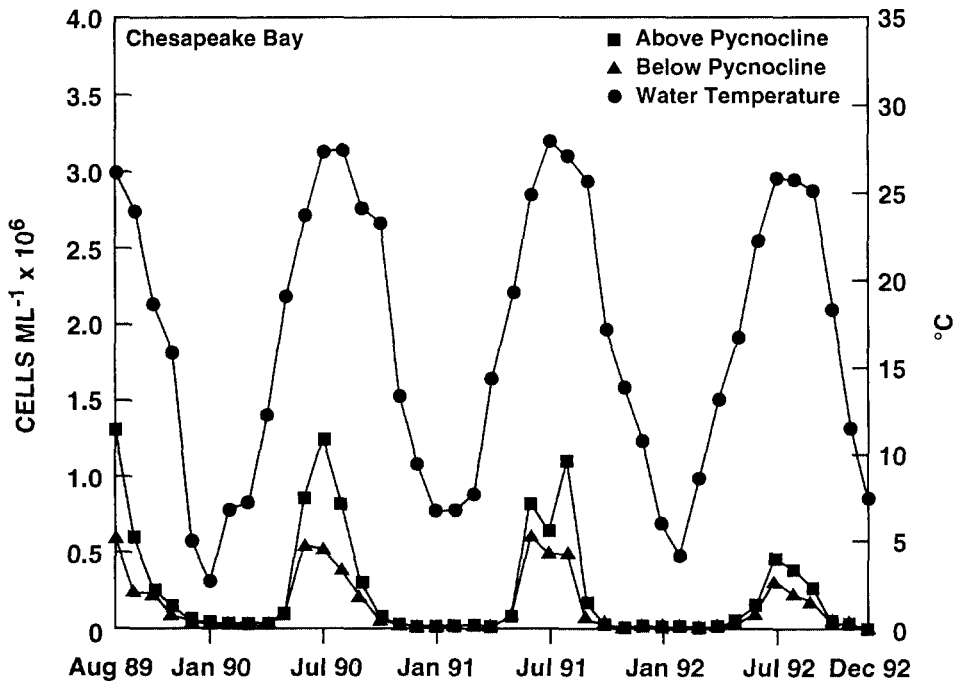

Figure 9. Mean concentrations of autotrophic picoplankton, for all stations, above and below the pycnocline, and mean surface water temperatures.

unimodal pattern of a summer maximum, where concentrations reached 10^5-10^6 cells ml^{-1}, to reduced mean levels of generally 10^3 cells ml^{-1} during other seasons. This growth pattern is similar to other marine studies where the maximum summer concentrations may come to 10^6 cells ml^{-1} (Waterbury *et al.*, 1986). At other sites, Jochem (1988) studied picocyanobacteria in the Kiel Fjord and Kiel Bight. He noted peak concentrations in July and August at 1.4-2.6 x 10^8 cells l^{-1}. Sondergaard *et al.* (1991) found the summer autotrophic picoplankton concentrations in the German Bight and Baltic Sea at 6 x 10^6 and 4.5 x 10^8 cells l^{-1} respectively. The base population levels in the Chesapeake Bay are more characteristic of those reported outside of estuaries. For instance, Stockner and Antia (1986) indicated increased surface concentrations in the North Atlantic progress to higher levels from oceanic, slope to coastal waters, as 10^6, 10^7, and 10^8 cells l^{-1} respectively. Fogg (1986) gave oceanic picophytoplankton concentrations levels at around 10^4 cells ml^{-1}, regardless of salinity, temperature or nutrient status, although he indicated highest concentrations would be in the more eutrophic sea waters. The parallel development of the cyanobacteria picoplankton with the rise of water temperature has been indicated by Waterbury *et al.* (1979), El Hag and Fogg (1986), and others.

In conclusion, the Chesapeake Bay has an abundant and ubiquitous autotrophic picoplankton component that is composed of mainly coccoid cyanobacteria and is present throughout the water column. They produce a single major peak in summer, that follows, but lags behind, the rise of the water temperature. The peak population abundance levels in summer are at the higher range (10^6 cells ml^{-1}) of concentrations that are common for marine waters, and are associated with favorable water quality conditions. Lower cell abundance levels at other times in Chesapeake Bay coincided with conditions that did not favor greater picoplankton development, e.g. reduced water temperatures of winter and spring. Seasonal spatial differences associated maximum picoplankton concentrations to higher temperatures and Bay areas having higher nutrient levels and lower salinities. Annual variations in abundance were also found.

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