PHYTOPLANKTON ABUNDANCE AND COMMUNITY SIZE COMPOSITION IN THE MIDDLE ATLANTIC BIGHT

by

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INTRODUCTION

Water over continental shelves make up 10% of the world's ocean but produce about 99% of the harvested fish (Ryther, 1969; Walsh, 1981; O'Reilly et al., in press). Due to their shallow nature, recycling of nutrients and phytoplankton production in overlying waters are much greater than that in adjacent oceanic waters. This, in addition to their tendency to concentrate fish, makes continental shelves highly productive (Walsh, 1981). Phytoplankton as the base of the food chain are very important to overall shelf productivity. Their importance is particularly noteable when examining their relationship to species of importance to man.

Reports of phytoplankton and their importance in the nutrition and survival of higher trophic levels are numerous. As early as 1914 Hjort proposed a relationship between the timing of spring bloom, the spawning of Norwegian spring-spawning herring and the success of year-class recruitment (May 1974). In the St. Lawrence Estuary zooplankton, particularly herbivorous copepods, are a critical link in the food web "between phytoplankton and larger animals of economic importance" Steven (1975). On the Labrador Shelf nutrient availability affects primary production which in turn affects food chain development from phytoplankton to zooplankton to small fish to cod (Sutcliffe, Jr. et al. 1983).

On Georges Bank the high level of fish production is, in part, traceable to the high level of primary production (Cohen and Grosslein, in press). In some areas the ratio of phytoplankton production to fish production is used to estimate size of fish stock which can be related to fish catch to determine the percentage of the community taken through fishing (Steven, 1975).

Studies on the west coast of the United States report the importance of phytoplankton to the northern anchovy. The dinoflagellate *Gymnodinium* *splendens* is a nutritionally important food source for first feeding northern anchovy larvae and the success of the year class may be partly dependent upon the availability of this organism or other dinoflagellates nutritionally comparable (Lasker 1981, 1978, 1975). Moffatt (1981) found that northern anchovy larvae grown on low zooplankton densities are able to survive and grow in the presence of a dense *Chorella* bloom and suggested that the algae provided additional nutrition needed for larval survival and growth.

Abundance of zooplankton which are food for larvae or fish can be affectd by phytoplankton availability. Most marine fish larvae feed on young stages of copepods (Hunter, 1981) and copepods feed on phytoplankton. In the Norwegian Sea the number of copepods and nauplii increased as "spring bloom" developed and "the copepods became so numerous that the increase in phytoplankton population undoubtedly was checked because of grazing" (Sverdrup, 1955). In the Davis Straight and the Labrador Sea Huntly et. al. (1983) concluded increases in zooplankton biomass resulted from consumption of "spring bloom". In the North Sea and northeast Atlantic herbivore (with the exception of *Calanus*) and phytoplankton abundance were strongly correlated and, in the study area, herbivorous plankton appeared more strongly regulated by food than predation (Koslow, 1983).

The purpose of this report is to characterize the phytoplankton communities in continental shelf and slope water in the Middle Atlantic Bight. The characterization of this area is based on chlorophyll *a* measurements, an index of phytoplankton biomass, made during 54 Northeast Fisheries Center surveys. Phytoplankton chlorophyll *a* and community size composition are examined. Phytoplankton are divided into netplankton (>20 um) and nanoplankton (<20 um) size fractions. Knowledge of the phytoplankton community size structure is "as important and probably more significant than total chlorophyll *a* in determining modes of transfer between trophic levels" (Steele and Frost, 1976).

Chlorophyll *a* distribution is described for five regions which have been delineated by bathymetry. They are designated as 1, 2, 3, 4, and 5 and represent the areas between 0-20, 20-40, 40-60, 60-200, and 200-2000 m (the slope seaward of the shelf break), respectively (Figure 1).

METHODS

Data on phytoplankton pigments included in this report were collected on 54 cruises from October 1977 through March 1982 as part of an extensive ongoing monitoring and assessment program to characterize the principal biological components of the fisheries of the northwest Atlantic continental shelf from Cape Hatteras to Nova Scotia. Generally, at each sampling location, water for pigment analysis was collected from standard depths of 1, 5, 10, 15, 20, 25, 30, 35, 50 and 75 m or bottom, whichever came first. After spring 1980, 100 m sampling depth was routinely sampled.

Aboard the research vessel samples were size-fractionated into netplankton (>20 um) and nanoplankton (<20 um) and analyzed for chlorophyll *a* using the fluorometric method described in Evans and O'Reilly (1983). The chlorophyll *a* concentration in the two size fractions was added to generate an estimate of the total chlorophyll *a* found at each depth sampled. The depth-weighted average chlorophyll *a* for the water column was calculated for each station sampled and then contoured.

In addition, to describe the general features of the annual cycle of chlorophyll *a* and size composition, data were pooled and averaged by month. The total amount of chlorophyll *a* found in the water column for each region as well as the percentage of total chlorophyll *a* (mg/m^3) in the nanoplankton size-fractions were graphed by month. The percentage of the total community chlorophyll *a* contributed by nanoplankton, the smaller phytoplankton, was determined by dividing chlorophyll *a* measured in the nanoplankton size fraction by total chlorophyll *a*. The coefficient of variability (CV) (standard deviation x 100) was calculated for each region. (January data for Regions 3 and 5 have not been included in statistical summaries since the number of samples was small.)

RESULTS

Region 1 (0-20 m)

Distribution of chlorophyll *a* over the generalized annual cycle was bimodal. The highest concentratons (7.44-7.23 mg/m^3) were found during the January-February period in the unstratified season. Broad secondary peaks were observed during September (4.97 mg/m^3) and during fall bloom in November and December (4.78 and 4.34 mg/m^3, respectively). Generally, chlorophyll *a* concentrations exceeded 3.00 mg/m^3 except during those months when stratification was present (May, June, and July) when the lowest values 1.75, 2.76, and 2.74 mg/m^3 were observed. Chlorophyll *a* concentrations clearly reached their low point in the annual cycle in May (Figures 2, 4; Table 1).

Netplankton dominated the communities throughout most of the year. They accounted for 71% of the standing stock during the February spring bloom and for between 55 and 62% of the standing stocks the remainder of the year except during May, June, July, and September when nanoplankton were dominant and accounted for 51-67% of the community chlorophyll *a*. In general, netplankton were dominant during the unstratified season (strongly in February, weakly the remainder of the season) and nanoplankton dominated the stratified season. Netplankton accounted for 54% of the annual chlorophyll *a* and were dominant eight out of 12 months.

Chlorophyll *a* concentrations in Region 1 were consistently higher than those in all other regions throughout the year (Figures 2, 4). The lowest concentration (1.75 mg/m^3) observed in this region was higher than the maximum (1.43 mg/m^3) observed during spring bloom in Region 5 and was close to the maximum (2.12) observed in Region 4.

Region 2 (20-40 m)

The generalized annual cycle of chlorophyll *a* in Region 2 follows the general bimodal pattern seen throughout the shelf. Averaged chlorophyll *a* concentrations were highest (3.84 mg/m^3) during the February "spring bloom". During the secondary November to December fall bloom, concentrations averaged 2.96 and 3.38 mg/m^3, respectively. A relatively high chlorophyll *a* concentration was also seen in August (2.10 mg/m^3). Chlorophyll *a* concentrations were relatively low during late spring and summer months of April, May, June, and July with chlorophyll *a* concentrations averaging 1.46, 1.05, 1.34, and 1.56 mg/m^3, respectively (Table 1).

As in Region 1, netplankton were responsible for greater than 50% of the total annual chlorophyll *a*. They dominated 7 of the 12 months accounting for 58% of the annual chlorophyll *a*, and again, as in Region 1 were slightly dominant over nanoplankton on an annual basis. Spring (February), fall (November-December), and late summer (August) maxima were all dominated by netplankton. As in Region 1, netplankton were strongly dominant during the February spring bloom accounting for 77% of the chlorophyll *a*. During the November-December fall bloom, netplankton and nanoplankton were present in near equal amounts, although netplankton were slightly dominant accounting for 54 and 60% of the chlorophyll *a*, respectively. Both February and November-December peaks were associated with the unstratified season.

The "summer maximum" observed in Region 2 differed in time and size composition from the summer maximum in Region 1. In Region 2 the maximum occurred in August, was predominately netplankton-dominated and was less prominent than the maximum observed during "spring" and "fall" blooms. In Region 1, the summer maximum was observed in September, was nanoplankton-dominated, and was comparable in magnitude to the November to December maximum. No summer maximum were observed in Regions 3, 4, and 5.

Region 3 (40-60 m)

Chlorophyll *a* concentrations in Region 3 were distributed in a bimodal pattern (Figure 2). The highest concentration of chlorophyll *a* (3.35 mg/m^3) was found in March during spring bloom. Again, a secondary bloom was observed in the fall during November and December with chlorophyll *a* concentrations averaging 1.98 and 1.76 mg/m^3, respectively. No peak was observed during summer.

Low concentrations of chlorophyll *a* were observed from May through September. The lowest concentration (0.82 mg/m^3) was observed in May. From June through September, chlorophyll *a* concentrations averaged roughly 1 mg/m^3.

Over the generalized year (excluding the two observations in January), chlorophyll *a* concentrations in the nanoplankton size fraction did not exceed 0.83 mg/m^3. Netplankton concentrations exceeded 1 mg/m^3 only during "bloom periods" and generally remained below 0.85 mg chl a/m^3 during the remainder of the year. Netplankton and nanoplankton were present in near equal quantities throughout most of the year but netplankton were often slightly more dominant than nanoplankton. In March during spring bloom, netplankton were strongly dominant and accounted for 70% of the averaged chlorophyll *a*. Over the annual cycle netplankton accounted for 56% of the total chlorophyll *a*.

Region 4

Total chlorophyll a concentrations were distributed bimodally in Region 4. As in Region 3, the higher standing stocks were found in March during spring bloom and during the November to December peak. Averaged concentrations during these months were 2.12, 1.01, and 1.22 mg/m^3, respectively (Figures 2, 4; Table 1). As in Region 3, the spring bloom was dominated by netplankton (accounting for 75% of chlorophyll a) and the fall bloom was slightly dominated by netplankton.

The lowest concentrations of chlorophyll a were present during the stratified season from May through September and in October. Nanoplankton clearly dominated the community during this time period, accounting for between 65 and 74% of the total chlorophyll a. This differs from Region 3 where netplankton and nannoplannkton were present in near equal quantities during this time period.

Over the generalized year, nanoplankton concentrations were fairly consistent, ranging from 0.41-0.62 mg/m^3. Netplankton concentrations were not as consistent over the annual cycles as those of the nanoplankton size fraction. They generally ranged between 0.14 and 0.69 mg/m^3, with the exception of March, when netplankton concentrations reached 1.59 mg/m^3. Concentrations less than 0.25 mg/m^3 were observed during the summer and early fall stratified season.

Nanoplankton slightly dominated the averaged annual chlorophyll a in Region 4, accounting for 52% of the total chlorophyll a. This stands in contrast to Regions 1, 2, and 3 where netplankton were slightly dominant on an annual basis.

When averaged total chlorophyll a are considered on a monthly basis, Region 4 (outer shelf) concentrations were always lower than those observed in Region 3, and higher than those in Region 5 (slope). This pattern was also observed with monthly averages for netplankton and nanoplankton fractions.

Region 5

In Region 5, as in Regions 3 and 4, monthly chlorophyll a concentrations were distributed in a bimodal pattern over the year with the higher chlorophyll a concentrations occurring during March (1.43 mg/m^3) and November to December (0.82 and 0.76 mg/m^3, respectively). Over the generalized yearly cycle, nanoplankton were dominant, accounting for 63% of the total annual chlorophyll a. However, the spring bloom, as in all other regions, was dominated by netplankton which accounted for 68% of the total average chlorophyll a. The fall bloom was slightly nanoplankton dominated (56%).

The lowest chlorophyll a concentrations were found over the slope during the stratified season from May through September, and in October. These monthly low values ranged from 0.35-0.61 mg/m^3 and averaged 0.54 mg/m^3. As in Region 4, nanoplankton dominated the stratified season accounting for 80% of the chlorophyll a during this time period.

Considering the yearly cycle, total chlorophyll a and nanoplankton chlorophyll a concentrations in Region 5 were consistently lower than those found in Region 4. Monthly nanoplankton averages ranged from 0.27 to 0.65, with an average of 0.39 mg/m^3. Average chlorophyll a in netplankton ranged from 0.04 to 0.36 mg/m^3, averaging 0.16 for all months except March when chlorophyll a concentrations reach 0.97 mg/m^3 during spring bloom.

DISCUSSION

Chlorophyll Distribution over the Middle Atlantic Bight Shelf

Autotrophic phytoplankton need light and nutrients to grow. Often one or the other is limiting and the effect, which is apparent in chlorophyll a data, increases with distance from shore and with increasing bottom depth. During late spring and summer the system is relatively stable. Few events occur to cause mixing, stratification occurs and a well-defined thermocline forms. During this time period solar energy for photosynthesis reaches its maximum; however, nutrient availability regulates phytoplankton production and the water column averaged chlorophyll a mg/m^3 is relatively low compared to other times of the year.

In general once the thermocline has formed the waters become divided into three layers, euphotic, thermocline and subeuphotic. The euphotic layer, which has a good supply of light is regulated by nutrient availability. Here, nutrients are generally supplied through recycling of organic matter and to a lesser extent from diffusion of nutrients across the thermocline (Harrison, 1980). The subeuphotic layer, which is below the thermocline, has a good supply of nutrients but is generally light-limited. Thus, conditions in neither of the layers surrounding the thermocline are ideal. However, chlorophyll a concentrations in the thermocline sometime exceed 10 times that found in waters above and below and much of the summer productivity occurs in this area of the water column (O'Reilly et al., in press). In the thermocline, light is generally sufficient for growth to occur and nutrients are supplied through diffusion from nutrient rich water below. Due to the high rate of primary productivity and high standing stocks of phytoplankton the area in and around the thermocline could be very important to larvae and zooplankton as a "feeding ground".

Different species of fish larvae and zooplankton have their own perculiar survival tactics but they all need food for survival. Availability of food is particularly critical for larval survival. Sea bass larvae when fed Artemia nauplic ate 40-60% of their own dry weight per day (Barahona-Fernandes, 1981). When larvae are able to feed before yolk exhaustion, they show a "substantial increase in growth and difference in morphological development" when compared to larvae starved or unable to feed early in development. (Ellertsen. et. al., 1981).

On the west coast success of anchovy year class is related to the strength of the thermocline, phytoplankton species composition within, and the stability of the water column. In 1976 when the water column was stable and the major phytoplankter was Gymnodinium splendens the anchovy year class was one of the best. In years when waters were unstable, the thermocline poorly established and diatoms the dominant phytoplankters, year class recruitment was poor. (Lasker, 1981, 1978).

Generally during the summer the layered distribution described above prevails over most of the shelf particularly in deeper more stable waters. However, nearshore in shallow waters where the system is more susecptible to mixing events, chlorophyll a distribution can be affected by events that introduce nutrient rich waters that stimulate growth. These events such as estuarine and coastal runoff, upwelling, downwelling, wind and tidal mixing lead to variations in the pattern described above (Evans-Zetlin et al., 1984). Frequently, in areas where there are high rates of vertical stirring or mixing, high concentrations of phytoplankton are found (McGowan and Hayward, 1978).

In fall the system becomes unstratified. The thermocline breaks down, the water column is mixed to the seabed, plant nutrients are plentiful throughout and phytoplankton, which are passive to vertical motions are distributed fairly uniformly throughout the water column. During this time period, the mean light intensity in the water column is decreasing, the euphotic zone becomes shallower and in general light becomes limiting. Since there is constant mixing throughout the water column, phytoplankton are in the euphotic zone part of the time and in the subeuphotic zone out of light the remainder. Going seaward as the bottom depth increases, the amount of time spent in the euphotic zone decreases and phytoplankton spend less time photosynthesizing and more time respiring.

Again, as in the nutrient regulated statified season, the effects are not as severe inshore. Because of the shallowness of the inshore area phytoplankton spend more time in the euphotic zone than their offshore counterparts and higher concentrations of chlorophyll a are observed.

During the unstratified season the highest standing stocks of phytoplankton occurr during spring bloom. Spring bloom which is composed primarily of netplankton probably is not eaten and eventually sinks and becomes part of the demersal food chain. During summer decomposition of phytoplankton on bottom may contribute to increased oxygen consumption and potential hypoxia.

Chlorophyll a (mg/m^3) is distributed over the shelf in a well-defined pattern. A gradient exists with high concentrations inshore (Region 1) and low concentrations offshore (Region 5) (Figures 2, 3, and 4). This pattern is generally present throughout the year with variations occurring in the magnitude of chlorophyll a present. The estimates of the average annual chlorophyll a (excluding January in Regions 3 and 5) for Regions 1-5 were 4.37, 2.26, 1.60, 0.94, 0.63 $mg/m^3/yr$, respectively, and support the generalization that phytoplankton chlorophyll a decreases from the shallow to the deeper areas of the MAB shelf. This pattern is also present in netplankton and nanoplankton data. Mean annual netplankton chlorophyll *a* concentrations decreased from 2.34 mg/m^3 in Region 1 to 0.22 mg/m^3 in Regon 5. Nanoplankton concentrations decreased from 2.03 mg/m^3 (Region 1) to 0.36 mg/m^3 (Region 5).

Despite the seven-fold decrease in total chlorophyll *a* concentration from nearshore to slope water, the overall month-to-month variability within each of the five regions was similar (coefficient of variability was 40, 42, 59, 48, and 52 for Regions 1-5, respectively). The coefficient of variability for netplankton was more variable and for nanoplankton less variable than that for total community chlorophyll *a*. Coefficients of variability for netplankton increased with depth and was 55, 60, 71, 91, and 113 for regions 1-5 respectively. Those for nanoplankton were similar except for region 4 and were 35, 28, 29, 14 and 28 for regions 1-5 resepctively.

In the Middle Atlantic Bight, the monthly distribution of chlorophyll *a* was bimodal with highest concentrations found in the spring (all regions) and secondary maxima found between November and December (all regions).

During spring when light intensity increases and nutrients are plentiful "spring bloom" is observed over the shelf generally between February and April. During this period the highest concentrations of chlorophyll *a* are observed. In the fall following breakdown of stratification and subsequent enhancement of the euphotic layer with nutrients trapped below the summer thermocline, light is still sufficient, and a secondary "fall bloom" occurs where chlorophyll *a* concentrations are lower than those found during spring bloom but higher than those found the remainder of the year. Additional maxima were seen in August and September in the inshore Regions 1 and 2. The lowest chlorophyll *a* concentrations were found during late spring and early summer at the onset of thermal stratification. In Regions 1 and 2, the lowest chlorophyll a concentrations occurred in May. In Regions 3, 4, and 5 chlorophyll a concentrations were relatively low from May through October.

On an annual basis, there is an onshore to offshore trend in phytoplankton community size composition that parallels the gradient in chlorophyll abundance. Over the annual cycle netplankton slightly dominated in Regions 1,2, and 3, whereas nanoplankton were slightly dominant in the outer shelf (Region 4) and clearly dominant over the slope (Region 5).

Netplankton are generally favored by extensive vertical mixing, are presumed to adjust well to "rapidly fluctuating irradiance conditions in well-mixed layers and have faster growth rate at lower temperatures (Walsby and Reynolds, 1980). Diatoms generally are dominant in colder, nutrient rich waters (Smayda, 1980). They strongly dominated phytoplankton chlorophyll a in all regions during the February to March spring bloom. During the November to December secondary maximum netplankton and nanoplankton were present in near equal amounts. Netplankton slightly dominated during the November to December secondary bloom in Regions 1-4 (shelf) while nanoplankton slightly dominated in Region 5, over the slope (Figures 2 and 4). Generally nanoplankton dominated during the warmer stratified season.

The above patterns in phytoplankton size and chlorophyll a distribution are supported by Smith (1973), Yentsch (1977) Shilling (1981) and Malone (1976).

SUMMARY

This paper provides a description of the phytoplankton community in waters over the continental shelf and slope. Average water column chlorophyll _a_ estimates from 54 cruises spanning the period of October 1977-March 1982 were pooled by area and month, irrespective of year, to form a synthetic year of averaged water column chlorophyll _a_ estimates. The area was divided into five subareas based on bottom depth to examine chlorophyll _a_ distribution. The regions and corresponding depths are: 1) 0-20, 2) 20-40, 3) 40-60, 4) 60-200 and 5) 200-2000 m (the slope seaward of the shelf break). NMFS phytoplankton data are not available for the region beyond the 2000 m isobath.

The annual cycle of chlorophyll _a_ was generally bimodal in all five regions examined. The highest chlorophyll _a_ concentrations over the entire shelf were consistently observed during the spring bloom during February (depths <40 m) and March (depths >40 m). The lowest concentrations were consistently observed from May through July in waters <40 m (Regions 1 and 2). At depths >40 m (Regions 3, 4 and 5) corresponding to mid to outer shelf and slope, chlorophyll _a_ concentrations were consistently low from May through October. A secondary peak in chlorophyll _a_ was observed during November and December across the entire shelf. Additional peaks of abundance were also observed in late summer for the two nearshore regions; during September, at depths <20 m and in August at depths between 20-40 m. During the stratified season in and around the thermocline a subsurface chlorophyll _a_ maximum is present, where relatively high concentrations of phytoplankton are available as food for zooplankton, During the unstratified season cholorophyll _a_ and phytoplankton generally are distributed evenly throughout the water column.

A recurring gradient in chlorophyll _a_ concentration was observed within

the monthly and annual chlorophyll _a_ averages. Highest chlorophyll _a_ concentrations were inshore (0-20 m) and the lowest were found at depths >200 m (Region 5).

Phytoplankton community size composition also varied over the year. Netplankton strongly dominated the February-March spring bloom over the entire shelf generally accounting for 70% of the standing stocks. In contrast, nanoplankton generally dominated communities during the mid-year stratified periods when chlorophyll *a* concentrations were at a low. During the fall bloom, netplankton and nanoplankton contributed to the phytoplankton community chlorophyll *a* in near equal amounts. In waters less than 200 m (Regions 1-4) netplankton slightly dominated the fall bloom, while in water >200 m (Region 5) nanoplankton slightly dominated but these differences probably are not of statistical significance.

At depths <60 m (Regions 1-3) netplankton were slightly more abundant than nanoplankton over the annual cycle. Nanoplankton were slightly more abundant between 60-200 m and nanoplankton clearly dominated the annual chlorophyll *a* at depths >200 m.

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