MID-ATLANTIC BIGHT NUTRIENT VARIABILITY

by

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INTRODUCTION

Continental shelves, which represent approximiately 10% of the area of the world's oceans, yield 99% of the global fish harvest. This is attributed to their shallow depth, which, as well as concentrating fish, promote the recycling of nutrients. Being at the very bottom of the food chain, nutrients therefore play a fundimental role in determining the biological potential and health of coastal areas.

Nutrient distributions in the Middle Atlantic Bight (MAB) are subject to a variety of controlling mechanisms, both physical and biological. These interacting processes result in an area continuously undergoing change on several different spatial and temporal scales. Superimposed on distributions due to larger influences are smaller-scale events, which can, under certain circumstances, intensify and alter overall patterns.

NUTRIENT IMPORTANCE AND ROLE IN PRODUCTIVITY

Fisheries production is ultimately dependent on phytoplankton productivity, which is largely controlled by the availability of nutrients (nitrogen, phosphorus, and silicon), light, and temperature. The interaction of these three elements on the continental shelf of the northwest Atlantic, results in one of the most productive ecosystems in the world (O'Reilly and Busch 1982).

Photosynthesis, or food production by phytoplankton, is limited to the illuminated surface layers of the sea, and is dependent on the presence of substances such as nitrogen, phosphorus, and silicon. The utilization of these nutrients by plankton in this photosynthetic or euphotic zone reduces water column nutrient concentrations and limits further growth of plankton populations. Some nutrients can be regenerated as planktonic organisms die or are grazed upon by zooplankton, with the resultant nutrients recycled within the euphotic zone. There can be however also a continuous loss of seasonal nutrients as phytoplankton sink below the euphotic zone, or are consumed by zooplankton and lost via zooplankton fecal pellets which sink below light active water depths. Nutrients, therefore, tend to accumulate in the deeper, darker layers of the water column where photosynthesis is minimal. Levels of production in the euphotic zone depend heavily on the rate at which these nutrients from enriched deeper waters are returned to the productive euphotic layer by mixing processes.

A distinction is often made between "new" primary production, based on nitrogen in the form of nitrate, and "old" primary production, based on nitrogen in the form of ammonium. Remineralization of dissolved and particulate matter to ammonium can occur both above and below the euphotic zone. During periods of poor vertical water exchange (summer in the MAB) when nutrient accumulations in deeper waters from previous seasons do not usually reach light active layers, "old" production, based on upper water column nutrient recycling, may be the prevalent mechanism for maintaining productivity levels. Winter and spring mixing of the water column in the MAB will make nitrate from deeper layers available to phytoplankton in the euphotic zone, resulting in a significant increase in "new" production.

Temperature, as well as directly affecting photosynthic rates, therefore influences productivity by influencing nutrient availability through water density. Density distributions can inhibit vertical mixing processes which restore nutrients to surface depleted layers. Summer warming of surface waters establishes a relatively stable density distribution. Below the warmed surface layer, waters are progressively cooler and therefore heavier as depths increase. The summer season is also associated with decreased storm activity, which at other times of the year would contribute to the break up of any layering. This water layering or stratification impedes vertical mixing and the exchange of nutrients between deeper nutrient-rich waters and the warmed nutrient poor surface layer.

Changing light and temperature regimes, and changing nutrient availability, therefore result in a seasonal cyclic pattern of primary production in the MAB. In the early spring, the water column is well-mixed and contains sufficient nutrients to support increased primary production as the intensity and availability of light increases, resulting in a spring bloom of phytoplankton. As surface water temperatures rise and the summer stratification of the water column develops and begins to retard nutrient transfer from deeper waters, phytoplankton concentrations increase next to the thermocline (the gradient representing the region in the water column of maximum temperature change with depth) and nutricline (the region in the water column of maximum change in nutrient concentration with depth) and decrease in surface layers. The breakup of these stratified conditions in autumn due to the cooling of surface waters and increased storminess gives a rise to a small bloom of phytoplankton before the decreased light availability and temperature again begin to severely limit the relative size of the plankton population. The effects of upwelling, water mass movements, estuarine discharge and organic waste disposal, are superimposed this seasonally changing productivity pattern and can alter the expected nutrient regime both temporally and spatially.

In other shelf areas the relative interactions between the three elements driving phytoplankton production (light, temperature, and nutrient availability) can be quite different. At tropical latitudes where elevated temperature and sufficient light exist year round, nutrient resupply from below the euphotic zone is the predominant factor regulating primary production, such as in the Peruvian shelf system where this resupply is heavily dependent on wind induced upwelling. In areas such as the western English Channel, strong tides result in permanently mixed waters and seasonal primary production cycles deviate from those on the Northwestern Atlantic Shelf (Wafar et al., 1983), which is subject to seasonal water column stratification and injections of nutrient richer slope water, which remains high in nutrient content year round.

DATA COLLECTION

The data contained herein are the result of extensive ongoing monitoring and assessment programs, conducted by the National Marine Fisheries Service's Northeast Fisheries Center (NEFC), to characterize the northwest Atlantic continental shelf, a region being subjected to ever increasing conflicting demands. The area under survey by the NEFC extends from Cape Hatteras to Nova Scotia, encompassing some 258,000 km^2. Over 18000 measurements of dissolved inorganic nutrient concentrations were extracted from this larger data set and reviewed in relation to nutrient variability in the MAB. The values were determined from filtered seawater samples collected between May 1979 and March 1980 on 11 cruises. Horizontal distributional maps were generated for each nutrient species at the deepest sampling level (bottom water for most stations, but not for all those where station depth exceeded 200 m), and for a weighted average of the upper one-fourth of the water column (but not exceeding 30 m in depth). Figure 1 indicates the distribution of station locations sampled during the period covered by this data set. Surveys were usually limited to the continental shelf to waters less than 200 m. Two cross shelf transects do fall within the area of interest (Figure 2). Transect 2 begins at the mouth of Delaware Bay and runs southeast as does Transect 3 which begins at the mouth of the Hudson River estuary.

NUTRIENT SPATIAL AND TEMPORAL VARIABILITY

Dissolved Inorganic Nitrite

Bottom water nitrate concentrations in the region remained higher than surface concentrations throughout the year, with the exception of localized influences of esturine plumes, such as in April 1979 when integrated surface layer concentrations were 5 to 10 times higher than bottom water values (Figure 4) at the mouth of the Hudson River estuary. Nitrate concentrations in bottom waters generally increase seaward, with isopleths of nitrate generally paralleling isobaths. Bottom water nitrate concentrations ranged from the limit of detection to over 50μM (micromoles) in the southeast region of the MAB. Values of from 0.1 to 10 μM were more common to the central region of the shelf.

The seasonal location of the 1 and 5 μM nitrate isopleths, which generally paralleled the coast, varied by about 100 km east-west over the year (Figures 2 and 3). Vertical profiles of nitrate concentration along Transects 2 and 3 demonstrated this movement, the expected stratification of the water column during warmer months, and well-mixed uniform conditions in early spring (Figures 5 and 6). The average location of the summer 0.2 μM contour line on these profiles generally corresponds with the mean depth of the euphotic zone (O'Reilly et al., 1981), indicating nitrate depletion by phytoplankton in the euphotic zone.

A tongue of nutrient-rich water extending along the bottom and up into the depleted surface layer is also indicated in the August 1979 nitrate profile along Transect 2 (Figure 5). This may be evidence of upwelling, which can be expected to occur during periods of southwesterly winds, and can be responsible for some replenishment of nutrient-depleted surface layers.

Integrated surface layer concentrations of NO_3 ranged from the limit of detection to 12 µM with values routinely ranging between 0.2 and 2 µM. Highest overall concentrations were observed in the spring and lowest in summer with several instances of estuarine influence indicated at the mouths of the Hudson, Delaware, and Chesapeake (Figure 7).

Dissolved Inorganic Nitrate

Bottom water nitrite distributions were not as uniform as those of nitrate and also did not parallel isobaths as well as nitrate isopleths. Concentrations ranged from the limit of detection to 8.4 µM nitrite in June at a station approximately 250 km southeast of the mouth of the Hudson River estuary. Values of 0.05 to 0.2 µM were more characteristic of the MAB throughout the year. In July a strong gradient from the mouth of the Hudson seaward (2 to 0.05 µM nitrite) was reflected in both bottom and surface layer distributions (Figure 8). Surface layer nitrate values ranged from the detection limit to 0.8 µM with most values falling between 0.05 and 0.2 µM as in the case of bottom waters. In August there was evidence of a weak gradient in the integrated surface layer extending from the Delaware River seaward, which was not strongly reflected in the bottom water nitrite distribution.

Ammonium Nitrogen

Ammonium nitrogen concentrations in bottom waters ranged from the detection limit to 9 µM with most observations falling between 0.2 and 1.5 µM . Elevated values were often associated with estuaries or spot sources. A gradient in ammonium nitrogen distribution was associated with the

Delaware River estuary during August, September, and October (Figure 9). Gradients associated with the mouth of the Hudson River estuary were also observed in April, September, and October as reported by Waldhauer et al. (1980). Integrated surface layer concentrations ranged from the detection limit to 16.5 μM with most values between 0 and 2 μM.

Dissolved Inorganic Phosphate

Bottom water values for phosphate in the MAB were as high as 1.7 μM. Generally, concentrations remained less than 0.6 μM inshore and increased seaward. Surface layer concentrations ranged up to 1.5 μM at the mouth of the Hudson River estuary in October. Most observations throughout the year, however, were between 0.1 and 0.4 μM. Both surface layer and bottom water isopleths were most uniform (parallel) to the coast in May. Surface layer waters did not exhibit the general increase in concentration seaward as did bottom waters, and in October the reverse was uniformly true with the highest phosphate concentrations found inshore and decreasing seaward (Figure 10). Vertical profiles along both transects demonstrated the expected mixed conditions in March, the onset of stratification in May continuing through September, and stratification break up in October.

Dissolved Inorganic Silicate

Observed bottom water silicate concentrations ranged from 0.3 to 24.4 μM, the lowest values generally occurring in March, being less than 1 μM in coastal waters and between 1 and 5 μM mid-shelf. Observed year-round bottom water silicate concentrations were more typically between 1 and 10 μM. The March silicate distribution, usually indicative of a well-mixed water column, was also the only period sampled that did not exhibit an area of reduced silicate concentration in bottom waters off the mouth of the Delaware River. Surface layer values of silicate ranged from 1 to 10.5 μM, more typically being between 2 and 5 μM in spring and early summer and less than one from mid-summer into the fall, when increases in overall concentrations were again indicated. Malone et al. (1980) have indicated that the end of the spring phytoplankton bloom in the New York Bight is controlled by this silicate depletion.

It should be kept in mind that the surface layer values reputed here are representative of a integrated portion of the water column and can mask smaller areas of total nutrient depletion, particulary in summer months. A forthcoming atlas of nutrient distributions over the continental shelf from Cape Hatteras to Nova Scotia is being prepared by NEFC's Environmental Chemistry Investigation at Sandy Hook. It will contain the specific data on which these observations are based as well as the individual figures generated for each nutrient speces. It will also represent a larger window or time span of observations which should permit a clearer determination of the timing and nature of changes in shelf nutrient distributions and relationships to phytoplankton production.

CONCLUSIONS

Data indicate the presence of several different processes influencing nutrient distributions and therefore primary productivity in the waters of the MAB. The seasonal stratification of the water column is reflected in the changingng nitrate distributions (Figure 11) with the resultant summer depletion of surface layer nitrate concentrations by phytoplankton. Tongues of nutrient-rich water can be extended along the bottom and up into this depleted surface layer by upwelling and can be responsible for some replenishment of these nutrient-depleted surface layers during periods of southwesterly winds. Discharge from esturies can also modify general nutrient distributions locally.

The seasonal variation in the location of 1 and 5 μM bottom water nitrate isopleths further indicate a large temporal variability in nutrients, seemingly slightly less in extent in the southern portion of the MAB than in its northern reaches. The scale of these variations (60 to 100 km) agrees well with the variability in the surface location of the shelf/slope front (50 km around the mean position) found by Guinn (1979) in examining satellite-derived thermal intepretations of frontal position (Ingham, 1976). From vertical profiles of nitrate distribution along Transects 2 and 3, we can project a zone on the shelf in which the 1 μM nitrate isopleth can be expected to be present at some depth in the water column, regardless of the season (Figure 2). The scale of this zone (10-20 km) and the shoreward-seaward migrations are characteristic of the scale of movement reported by Wright (1972) for the seasonal change in location of the average bottom water position of the shelf/slope front. Frontal influences are therefore indicated in the nutrient data and it appears that bottom waters on the shelf are strongly influenced by cross-shelf transport of slope water rich in nutrients.

Relatively high levels of primary productivity are sustained shelf-wide throughout the summer despite the formation of a nutrient-depleted surface layer (O'Reilly and Busch, 1981). Stratification of the water column at this time of year would be expected to greatly reduce nutrient-rich bottom waters and the replenishment of nutrient-depleted surface layers. Nutrient regeneration in the upper water column at this time may therefore be the crucial process for the maintenance of phytoplankton stocks and productivity rates in the region resulting in "old" production prevalence. Walsh (1981) has suggested that 46% of the New York Bight annual primary production nitrogen demand may be supplied by recycling, indicating a closer association between the shelf pelagic food web and the demersal food web than those of some other shelf ecosystems. Significant production also takes place deeper down in the subsurface chlorophyll maximum layer next to the thermocline. Nutrients are probably more available at the thermocline than in surface waters, and while light availability is limited, it is often still adequate for growth and can be offset by phytoplankton abundance and nutrient availability. At other times of the year and in the case of upwelling and onshore movement of nutrient-rich waters, water mass transport may be the dominant factor in regulating primary production and determining the quantities of nutrients available for assimilation by phytoplankton. Walsh et al. (1978) have in fact observed a doubling of phytoplankton standing crop as a response to storm initiated nutrient injection at the shelf slope break, and have postulated that storm induced mixing and upwelling of nitrate may satisfy at least 30% of the productivity demand of the bight system.

Such nutrient limitation or stimulation of phytoplankton populations can be expected to have significant effects further up the food chain, as well as in critical summer situations when a population explosion of a specific phytoplankton species can contribute to an anoxic event with associated marine life mortality.

SUMMARY

Nutrient distributions in the MAB exhibit a high degree of spatial and temporal variability. They are characterized by a seasonal cycle with a summer stratified water column producing a surface layer, seemingly extending to the depth of the mean euphotic zone, depleted by nutrients by phytoplankton activity. Primary production rates however remain high, possibly do to rapid nutrient recycling in the upper water column and/or to phytoplankton activity in the area of the nutricline. Fall break up of stratified conditions results in a vertically well-mixed water column through the winter and spring months making possible the resupply of nutrient-rich waters to the upper light receiving and active layers of the water column. In general, nutrient concentrations in bottom waters are higher than those in surface layers. Inshore waters undergo relatively larger changes in concentration than bottom waters over the eastern extent of the shelf, which tend to remain high year-round. Nitrate distributions, in particular, exhibit a general increase seaward year-round. Slope waters rich in nutrients were an ever present reservoir of nitrogen which can replace nitorgen utilized on and/or lost from inshore waters. Cross shelf transport of this water, upwelling, and estuarine discharge can be influencial in determining the distribution of a specific nutrient species at a given place and time with resultant effects on productivity and energy transfers to higher trophic levels.

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