SIZE STRUCTURE OF PHYTOPLANKTON AND NUTRIENT ENRICHMENT IN THE EQUATORIAL ATLANTIC OCEAN

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ABSTRACT

A study of the size structure of chlorophyll a (Chla) covering the major part of the equatorial Atlantic ocean from 5°N to 5°S leads to the conclusion that the seasonal nutrient enrichment in the open eastern equatorial Atlantic does not drastically affect the size distribution of the primary producers. 90 % of the total Chla are everywhere contained in the < 10 µm fraction on the average.

These new results confirm the previous suggestion that the structure of the food web would not change with the seasonal and geographical variations in oceanic regimes. Therefore, from an ecological point of view, the term "upwelling" is misleading and the open equatorial (and probably tropical) Atlantic ocean can be considered as a unique ecosystem.

1 - INTRODUCTION

The trophic organization of pelagic ecosystems has long been recognized as an important consideration in assessing the ultimate yield of the oceans in terms of fisheries. It is generally agreed that the larger the plant cells at the beginning of the food chain the fewer the trophic levels that are required to convert the organic matter to useful form to man (Ryther, 1969 ; Landry, 1977). Therefore, the first factor to be considered in this context is the size of photosynthetic organisms.

The coastal environments, and specially the upwellings where nutrients are available in high concentration, are characterized by episodic pulses in phytoplankton biomass caused by large-celled diatoms and dinoflagellates or chain forming diatoms that are retained by 10-20 µm mesh screens (i.e. netplankton). Accordingly, the great production of fishes in the coastal upwellings results not only from higher values of net primary production, but also from the small number of trophic levels between phytoplankton and fish.

In contrast the small solitary forms passed by 10-20 µm mesh screens (i.e. nanoplankton) account for most phytoplankton biomass in the open ocean where about 80% of the global marine phytoplankton production occurs (Malone, 1980). Recently, it has become increasingly apparent that very small organisms less than 2 µm in diameter and called "picoplankton", (Sieburth et al. 1978) constitute an important fraction of the autotrophic biomass in the tropical and subtropical open ocean (Li et al. 1983, Platt et al. 1983, Herbland et al. 1985).

Results presented here support the hypothesis that the vertical motion in the equatorial upper Atlantic does not disrupt the size structure of the phytoplankton community. In other words, the expression "upwelling" has not, from a biological point of view, the same meaning in the coastal and the open sea.

2 - MATERIAL AND METHODS

The data have been collected during the cruises FOCAL 4, 6 and 8, respectively in July-August 1983, January-February 1984 and July-August 1984. For comparison, some samples were collected near Dakar (Senegal) during the period of upwelling (early 1985).

The method used for chlorophyll a analysis has been described in details elsewhere (Herbland, Le Bouteiller and Raimbault, 1985). Methanol was used for extraction instead of 90 % acetone. It allows a total and rapid extraction without grinding and it avoids the centrifugation step (Holm Hansen and Riemann, 1978). Nuclepore filters (porosities of 10 µm and 1 µm in the present study) have been used for fractionation. The total chlorophyll a was measured on whatman GF/F fiber glass filters.

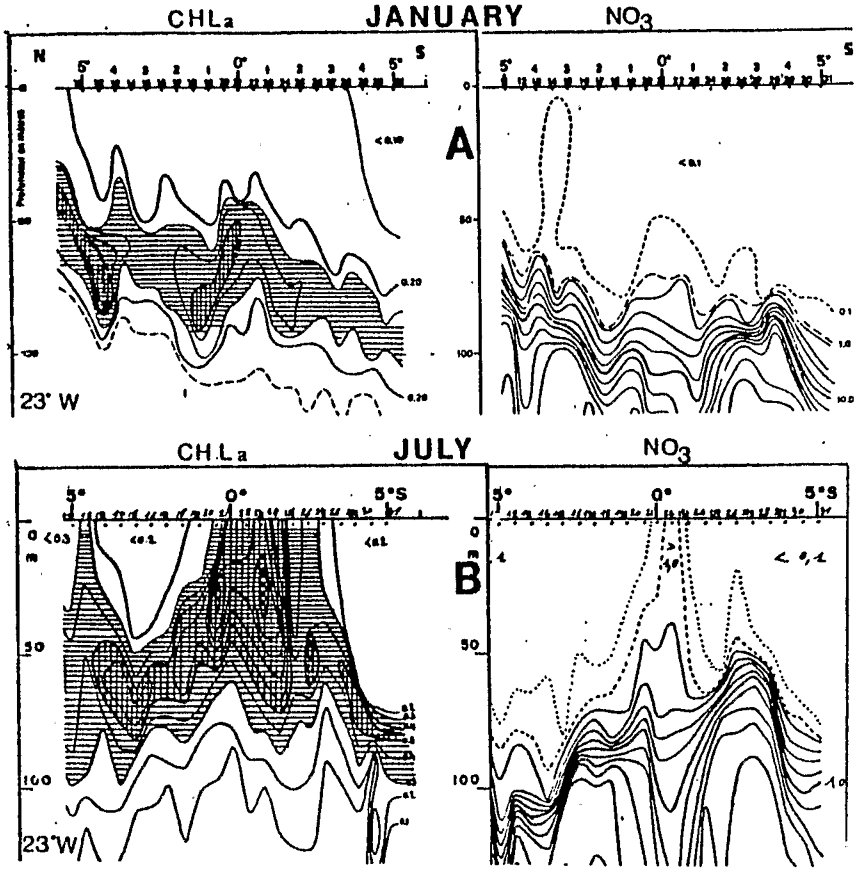

fig. 1 Vertical distribution of Chla (on the left) and nitrate (on the right) between 5°N and 5°S at 23°W. Chla : $\mu g l^{-1}$; NO_3^- : $\mu gat. l^{-1}$ Upper panel : FOCAL 6, "Warm season" January 1984, lower panel : FOCAL 8, "cold season" July 1984. A similar distribution was observed at 4°W.

3 - RESULTS AND DISCUSSION

3.1 Influence of the equatorial upwelling on the Chla distribution.

Results presented in figure 1 (section at 23°W), show clearly that the seasonal variations of the vertical distribution of nitrate affect the Chla distribution. In January 1984 (i.e. during "warm season") the bulk of Chla was found in a layer of about thirty meters depth located within the upper part of the nitracline (fig. 1A). It is the Typical Tropical Structure as described by Herbland and Voituriez (1979) in which the Deep Chlorophyll Maximum (DCM) is principally governed by turbulent mixing and nutrient supply rate from below, with an active balance of nitrate fluxes (Cullen, 1982 ; Abbott et al., 1984). In July 1984 (i.e. during the "cold season") the vertical motion of the nitracline caused the rising of the DCM which reached surface between 0°30-N and 3°30 S (fig. 1B). In 1984, the chla values were significantly higher in July than in January, but this would not be the rule : from 0° to 5°S at 4°W, there was no significant seasonal difference between winter and summer integrated values of Chla from 1977 to 1979 (Voituriez et al., 1982) and in 1982 and 1983 (unpublished data).
However, the Chla concentration never exceeded 1.5 $\mu g l^{-1}$. Available CZCS images in that region confirm the absence, at least for summers 1983 and 1984, of values greater than 2-3 $\mu g l^{-1}$ (Carder, personal communication).

Therefore, our present data confirm the previous measurements over 10 years in the Gulf of Guinea by the ORSTOM's teams : both the intensity of surface nutrient enrichment and the maximal Chla concentrations in the equatorial upwelling are at least one order of magnitude lower than in the coastal Northwest Africa upwelling.

3.2 Size structure of Chlorophyll a.

3.2.1. The netplankton (>10 µm).

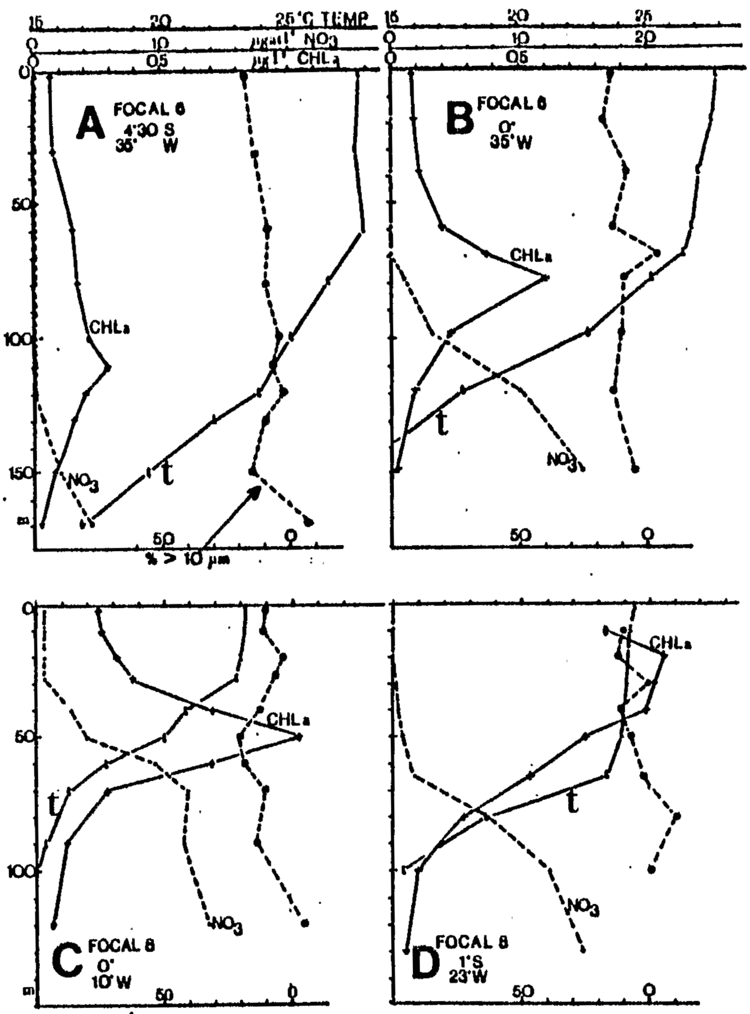

fig. 2 Vertical distribution of temperature (t), nitrate (·---·), chlorophyll a (+--+) and percentage of > 10 µm Chla (o--o) at four stations in the equatorial Atlantic.

Size separations on a 10 µm filter has been realized at 9 stations on 8-10 levels. Four representative structures are selected in figure 2, from the weak and deep chlorophyll maximum located at the bottom of a nitrate-depleted layer (but not uniform in temperature) at 35°W (fig. 2A) to the typical Chla distribution in the upwelling with values greater than 1 $\mu g.l^{-1}$, in the subsurface layer (fig. 2D). It is clear that the percentage of > 10 µm Chla rarely exceeds 15 %.

Similarly, the percentage of > 10 µm Chla is not affected by the total Chla value (fig. 3) : the percentage of netplankton does not increase with increasing total Chla values.

In contrast, for the same range of Chla concentrations (0-2 $\mu g.l^{-1}$), the percentage of < 10 µm Chla is significantly lower in the surface upwelled water near Dakar. Moreover the percentage seems to slowly decrease when the total Chla values increase.

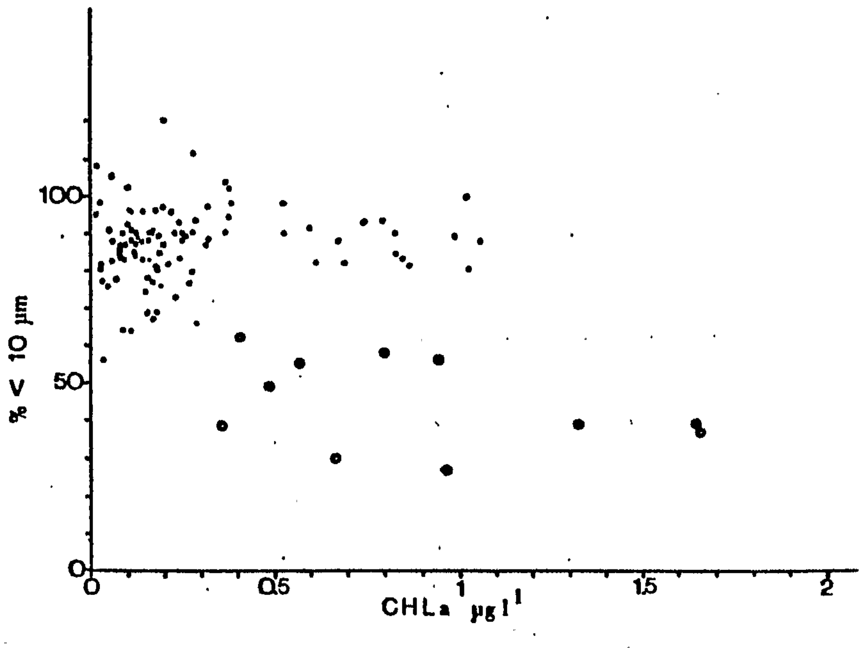

fig. 3 Relationship between the total Chl$\underline{a}$ concentration and the percentage of < 10 µm Chl$\underline{a}$, between 0 and 2 µg.l^{-1}. Dots : open equatorial Atlantic ; open circles : coastal upwelling near Dakar (Sénégal).

3.3.3. The picoplankton (0.2 - 1 µm).

On figure 4, we have selected 4 categories of samples according to their position in the water column and in the nutrient structure. Although there is a small overlapping, it clearly appears that the deep and weak chlorophyll maxima located at the bottom of the nitrate-depleted layer at 35°W and 28°W (open circles) contain the highest proportion of picoplankton. In contrast, it is not possible to separate, from this size criterion, the deep chlorophyll maxima located at the top of the nitracline during the warm season (crosses) from the subsuperficial maximum of the equatorial upwelling (dots). In the coastal samples (c) the percentage of picoplankton never exceeds 20 %.

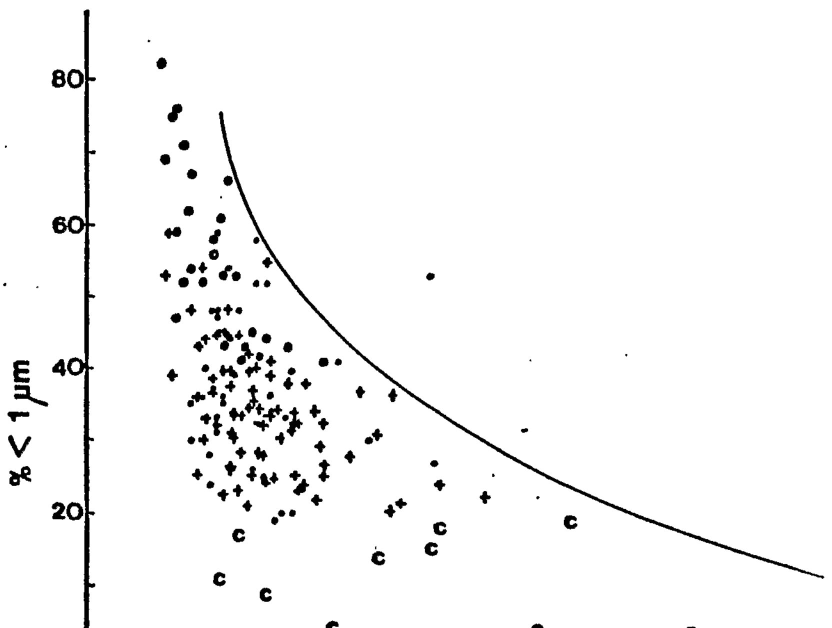

fig. 4 Relationship between the total Chla concentration and the percentage of < 1 µm Chla between 0 and 2 µg.l^{-1}. Open circles : Deep chlorophyll maxima in a nitrate-depleted layer ; crosses : Deep Chlorophyll maxima in the TTS, with nitrate ; dots : Subsurperficial maxima in the equatorial upwelling ; (c) : coastal upwelling near Dakar.

This figure allows the drawing of a line (one point excepted) which represents the maximum expected percentage of <1 µm Chl*a* for a given Chl*a* concentration ; this line confirms that the high values of Chl*a* are not due to picoplankton blooms, or, in other words, that picoplankton blooms are unlikely in the tropical Atlantic.

Our results show that the commonly called "equatorial upwelling", at least in the eastern Atlantic, does not bring about a phytoplanktonic development comparable neither in intensity nor in quality with blooms observed in coastal upwellings. In the whole equatorial area covered by the FOCAL cruises, the mean >10 µm Chl*a* does not exceed 15 % and the total Chl*a* concentration was typically less than 1.5 $\mu g.l^{-1}$. For a given Chl*a* concentration and in the presence of nitrate, the percentage of picoplankton is the same in the deep Chla maximum at 23°W during the warm season and in the subsuperficial Chla maximum of the equatorial upwelling.

In a previous study, we pointed out that the picoplankton dominates (71 % on the average in terms of Chl*a*) in the nitrate-depleted layer whereas its relative importance decreases in the Chl*a* maximum where the nanoplankton composes the bulk of the biomass (Herbland et al. 1985). Since the equatorial upwelling results in the vanishing of the nitrate-depleted layer, there is, for the whole euphotic.layer, a slight increase (x 2 ?) in the mean cell size of phytoplankton, which probably has only mild, if any, effect on the trophic organization of the ecosystem.

Our results are consistent with prior observations in the same region dealing with the size structure of zooplankton (Voituriez et al. 1982) the relationship between phytoplankton and zooplankton (Le Borgne, 1981) the properties of diverse biochemical and physiological indices of zooplankton (Le Borgne and Roger, 1983) and the nitrate/temperature linear relationship (Voituriez and Herbland, 1984). All these observations were unable to point out any difference between the two seasons in the eastern equatorial Atlantic.

CONCLUSION

After ten years of intensive chemical and biological measurements in the eastern equatorial Atlantic ocean, we lead to the conclusion that the seasonal upwelling itself has not an important effect on the intensity of the primary production. During the warm season (8 months over 12) the nitracline remains sufficiently close to the surface to allow the maintenance of a deep chlorophyll maximum in which the bulk of the primary production occurs. The seasonal upwelling seems to be nothing else that the coming into surface of the deep chlorophyll maximum without appreciable enhancement of its value and modification of its trophic organization.

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