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Size distribution and abundance of phytoplankton in the Pacific equatorial upwelling

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Abstract: In January 1991, the equatorial Pacific enrichment area covered a belt more than 11000 km long, with surface nitrate concentration up to 11 μM near the Galapagos islands, decreasing westwards and desappearing beyond 167°E. In this area, the amount of chlorophyll *a* (Chla) did not change significantly from one end of the upwelling to the other, and was very low everywhere. The size structure of chlorophyll *a* was also nearly constant from 95°W to 167° E : on the average, Chla >3μm and Chla<1μm represented 27% and 39% respectively all along the equator, with correlative uniform distributions of phycoerythrin-containing cyanobacteria (*Synechococcus* sp.) and chlorophyll-fluorescing microalgae.

Schematically, in spite of the typical longitudinal gradients of temperature and nutrients, all data of chlorophyll, size distribution and cell numbers cliarly indecate that an extreme monotony characterizes the distribution of phytoplankton all along the enrichment area due to the equatorial upwelling, covering 11 million km^2 for mean upwelling conditions.

1. Introduction

Various recent studies have shown that in the tropical open ocean, the size structure of phytoplankton seemed to be typically distributed (HERBLAND *et al.*, 1985, 1987; PEÑA *et al.*, 1990; LE BOUTEILLER *et al.*, 1992). In the nitrate depleted mixed layer of the equatorial Atlantic Ocean as well as in the one of the western Pacific Ocean, Chl a in the <1 μm fraction was found to be always predominant.In the nutrient-rich waters, more than half of the total Chla was systematically contained within the >1 μm fraction in which eucaryotic microalgae predominated. No major difference distinguished phytoplankton forming the deep chlorophyll maximum from phytoplankton observed in surface waters enriched by the equatorial upwelling. On the contrary, the size structure of phytoplankton usually observed in these nutrient-rich tropical waters is quite different from the size of algae in coastal upwellings (HERBLAND et al., 1987) or in temperate or cold nutrient-rich waters (STOCKNER and ANTIA, 1986; RAIMBAULT *et al.*, 1988). Therefore, the size distribution of phytoplankton would be one of the most significant properties of the Typical Tropical Structure such as defined by HERBLAND and VOITURIEZ (1979).

However, such a generalization is always risky as far as the size structure of phytoplankton is not determined everywhere in the tropical ocean, and especially in the poorly known Pacific equatorial upwelling. So, a wide study of the distribution of phytoplankton associated with physical and chemical properties, was performed during the ALIZE cruise stretching all along the equator from 95° W to 165° E.

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2. Methods

All the methods used were described by REVERDIN *et al.*(1991). Total Chla (100ml) was collected on GF/F filters at 9 or 10 depths. Chla in the fractions was estimated on subsamples (260 ml) filtered on Nuclepore polycarbonate filters (1 and 3 μm), always at<30 mm of Hg vacuum pressure. Samples for cell counts (60 ml) were collected according to BLANCHOT *et al.*(1992) on black 0.2 μm Nuclepore filters. All filters were frozen for a later analysis at the laboratory: Chla with the methanol method and cell counts by epifluorescence microscopy.

3. Results and discussion

Position of the stations is shown on Fig. 1. The equatorial upwelling was well developed in January 1991. Nitrate was present at surface (NO_3> 0.1 μM) at every station from 95° W (maximum 11 μM) to 169° E and on all the meridional transects, except south of 11° S at 150° W and westwards beyond 168° E (Fig.2). Surface temperature rised from 22° 8 C at 95° W to 29° 4 at 173° E.

The amount of surface Chla (mean for the 0-20m layer) did not change significantly from one end of the upwelling to the other,

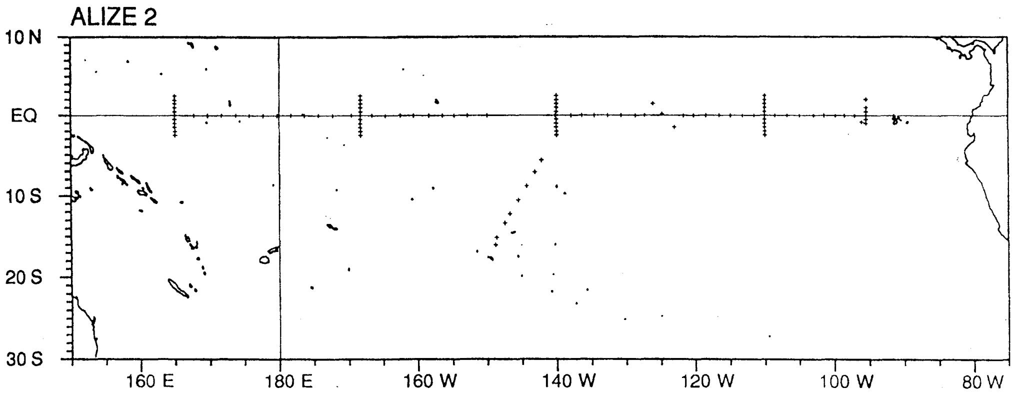

Fig. 1. ALIZE II cruise. January-Fabruary 1991. Location of stations from 95° W to 165°E

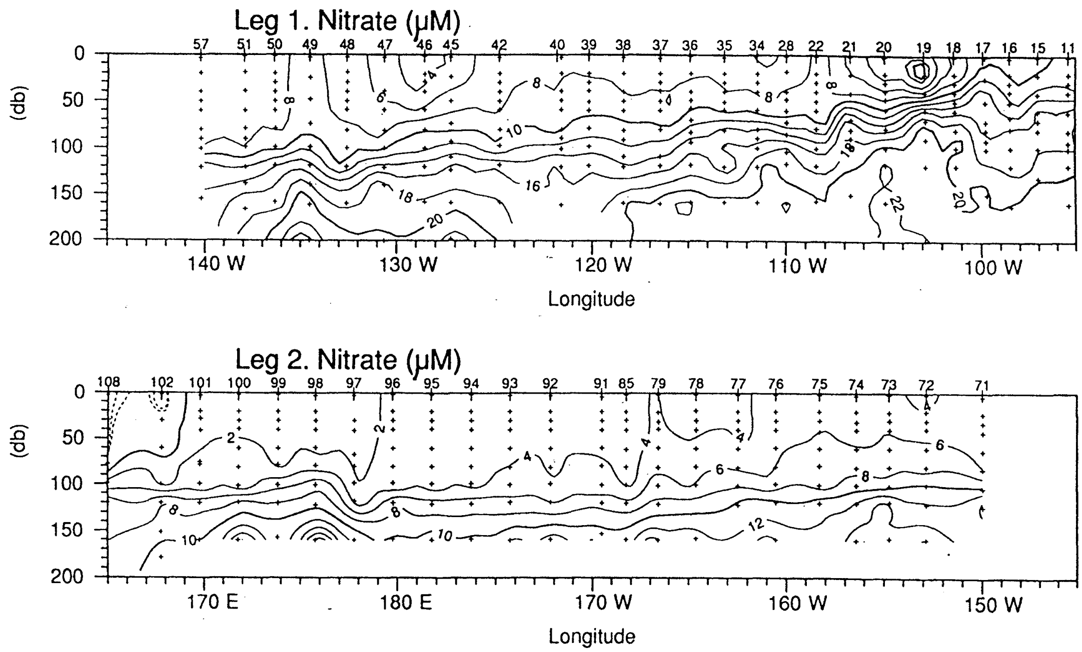

Fig. 2. Nitrate distribution (μM) along the equator.

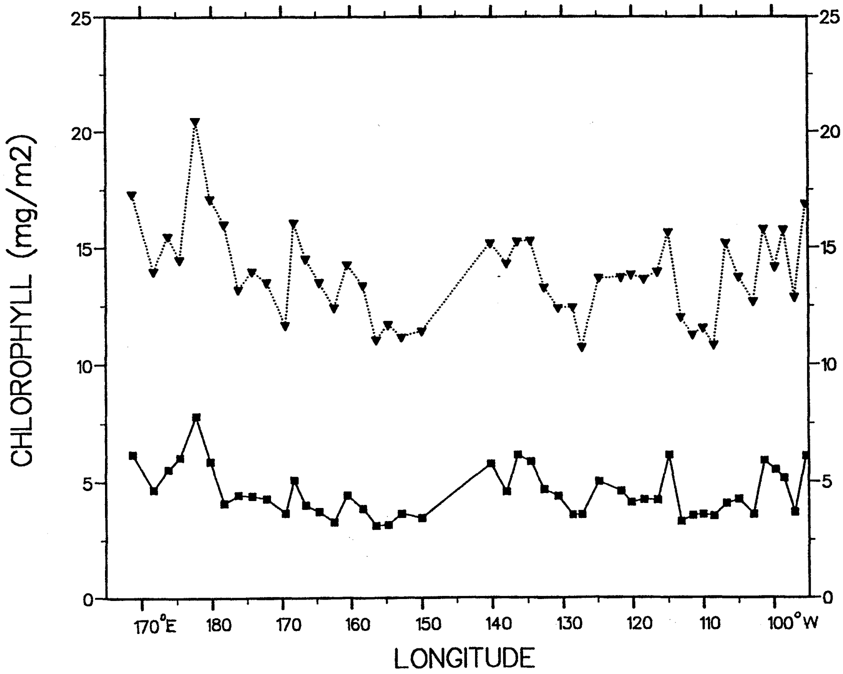

Fig. 3. Depth integrated values of chlorophyll a along the equator ($mg\,m^{-2}$). Squares: 0-20m layer. Triangles: euphotic layer.

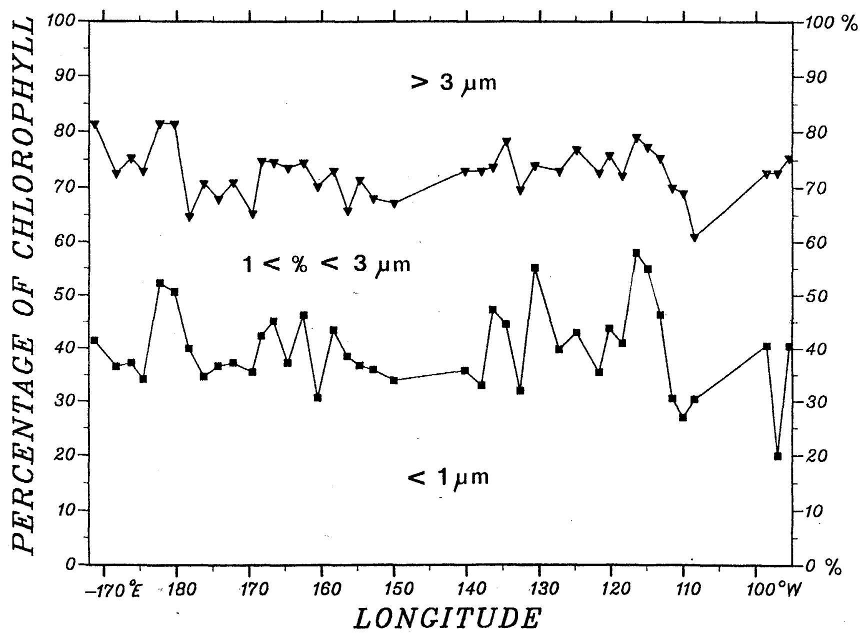

Fig. 4. Relative size distribution of Chla within the euphotic layer along the equator.

and was very low everywhere: Chla=0.215 mg m^{-3} (mean of 55 stations) from 95° W to 145 ° W, and Chla=0.218 mg m^{-3} (n=35 stations) from 150° W to 169° E (Fig.3). Surface Chla maximum was only 0.402 mg m^{-3}. These values are quite similar to those obtained by the same method at 165° E during the 6 transects of the ORSTOM programmes (i.e. PROPPAC and SURTROPAC) which have crossed the equatorial upwelling since 1988: surface Chla (0-20m layer)=0.231 mg m^{-3} (mean of 57 stations).

During the ALIZE I cruise in 1965, covering the same area as ALIZE II, the equatorial upwelling presented nearly the same spreading (GUEREDRAT, 1971). Chla was collected on Millipore HA 0.45 μm filters and analysed on a spectrophotometer after acetone extraction. The mean surface Chla (0-20m layer) was 0.192 mg m^{-3} (n=17) from 94° W to 140° W and 0.194 mg m^{-3} (n=13) from 146° W to 174° E, without any high Chla value in nutrient-rich waters, even when surface NO_3 was up to 13 or 14 μM at 95° W.

The Chla content of the euphotic layer was calculated according to MOREL (1988). The mean values were respectively 13.1 and 13.8 mg m^{-2} in the eastern and western parts of the Pacific in 1991 (Fig.3), and 14.3 mg m^{-2} at 165° E

These depth distributions of Chla are quite similar to those reported by CHAVEZ *et al.* (1990), showing low Chla values along the equator from 110° W to 140° W. CULLEN *et al.*(1992) also observed similar Chla profiles at 0°, 150° W. CHAVEZ and BRUSCA (1992) presented means of surface mitrate and surface Chla along the equator calculated on data collected from 1980 to 1988: surface Chla concentrations are regularly low from west of the Galapagos to the end of the upwelling, near 165° E.

The size structure of chlorophyll *a* appeared nearly constant from 95° W to 167° E: on the average, Chla > 3 μm represented 27% and 28% of total Chla in the eastern and western equatorial Pacific respectively, and never exceeded 39%. Chla <1 μm=39% (mean of 42 profiles) all along the equator (Fig.4). These size distrbutions are not different from those observed at 165° E in the western part of the equatorial upwelling by LE BOUTEILLER *et al.* (1992): Chla <1 μm=38% (n=26). PENA *et al.*(1990) also found that Chla <1 μm = 40% on the average (n=6 profiles) in the upwelling at 135° W, but CHAVEZ (1989) reported a mean Chla content of 62.4% in the < 1 μm fraction at 110° W(n=6), which seems atypically high for equatorial nutrient-rich waters.

Besides, counts of cells by epifluorescence microscopy at 48 hydrocasts distributed between 95° W and 169° E revealed that the euphotic zone contained on the average 4.2 10^{11} cyanobacteria per m^2 and 2.1 10^{11} eucaryotic microalgae per m^2, without any bloom anywhere.

Consequently, in spite of the typical longitudinal gradients of temperature and nutrients showed by the equatorial transects of both ALIZE I and ALIZE II cruises and by the analysis of historical data, all the biomass indexes available today clearly indicate that an extreme monotony characterizes the distribution of phytoplankton all along the enrichment area due to the equatorial upwelling. Exactly the same experimental procedures were used to perform the Chla fractionations and the cell enumerations during the ALIZE II cruise, so that the phytoplankton properties are described as reliably as possible from 95° W to 165° E. The relative abundance of large algal cells such as diatoms observed in the eastern equatorial Pacific by DESROSIERES (1969) and CHAVEZ *et al.* (1990) or suspected by BENDER and MCPHADEN (1990) seem to be locally and temporally restricted, and do not induce significant changes of Chla (<1 μm, >3 μm and total) or cell numbers (cyanobacteria and eucaryotic microalgae) from the west of the Galapagos to the end of the upwelling.

As a conclusion, when mean conditions prevail, the typical monotonous distribution of phyto-plankton strongly suggests that primary production, new production and particles exportation are probably also uniformly distributed through the pacific equatorial system.This result is important to be considered in the near future, especially for global scale studies such as the JGOFS programme.

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